Assessment of Techniques for Rainbow Trout Transplanting and Habitat Management in British Columbia

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ASSESSMENT OF TECHNIQUES FOR RAINBOW TROUT TRANSPLANTING AND HABITAT MANAGEMENT IN BRITISH COLUMBIA

by

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TABLE OF CONTENTS

Table of Contents iii
List of Tables v
List of Figures v
List of Plates v
List of Appendices v
Abstract vii
Acknowledgments viii
Disclaimer x

1.0 INTRODUCTION 1

2.0 METHODOLOGY 3

3.0 RAINBOW TROUT 5

3.1 Species Diversity 5
3.2 Environmental Requirements 6
3.2.1 Life history linkages and habitat connections 6
3.2.2 Water quality requirements 6
3.2.3 Gravel 6
3.2.4 Stream bed stability 7
3.2.5 Flow regime and water depth 7

4.0 TRANSPLANTING RAINBOW TROUT TO BARREN LAKES 9

4.1 Quantification of British Columbia Provincial Lake Habitat 9
4.2 Assessment of Productive Capability 11
4.2.1 Introduction 11
4.3 British Columbia Provincial Stock Transplanting Techniques 12
4.4 Winterkill 12
4.4.1 Introduction 12
4.4.2 Processes responsible for winterkill 13
4.4.3 Factors influencing the incidence of winterkill 14
4.4.4 Review of previous British Columbia provincial aeration projects 16
4.4.5 Design of British Columbia provincial aeration projects 16
4.4.6 Stocking winterkill lakes 17
4.5 Summerkill 18
4.6 Conclusions 18

TABLE OF CONTENTS continued

5.0 RAISING LAKE LEVELS, AUGMENTING LAKE INFLOW OR CREATING NEW LAKES 21

5.1 Literature Review 21
5.1.1 Indices of productivity 21
5.1.2 Importance of basin morphometry 22
5.1.3 Conditions in reservoirs with water level fluctuation 23
5.1.4 Conditions in reservoirs with stable water levels 24
5.1.5 Effectiveness of littoral areas as over-winter refuge habitat 25
5.2 Review of Constructed Projects 25
5.2.1 Project success 25
5.2.2 Factors affecting project success 26
5.2.3 Summary 27

6.0 CONSTRUCTION OR ENHANCEMENT OF SPAWNING/REARING CHANNELS 29

6.1 Techniques for Quantifying Stream Spawning and Rearing Habitat 29
6.2 Review of Previous Projects 31
6.3 Factors Affecting Project Success 34

7.0 PHYSICAL AND ECOLOGICAL EFFECTIVENESS OF DIVERSION CHANNELS AROUND PITS, ROCK DUMPS AND TAILINGS OR SETTLING PONDS 35

7.1 Review of Previous Projects 35
7.2 Factors Affecting Project Success 35
7.3 Recommendations for Design of Ecologically Functioning Diversion Channels 36
7.3.1 Hydrology and hydraulics 36
7.3.2 Biological considerations 36

8.0 CONCLUSIONS 39

9.0 SOURCES OF INFORMATION 41
9.1 References 41
9.2 Personal Communications 52

LIST OF TABLES

1 Water quality requirements for rainbow trout 55
2 Success summary, lake aeration projects 56
3 Success summary, lake level and flow projects 57
4 Success summary, spawning and rearing channel projects 58/59
5 Success summary, ecologically effective diversion channels 60

LIST OF FIGURES

1 Yield and/or biomass curves for four regional lake groups 61
2 Rate of oxygen depletion during winter as a function of mean depth of the lake 62
3 Relationship between the rate of oxygen depletion during winter and the sediment area:lake volume ratio 62
4 Historical changes in channel morphology, Theodosia River (B.C.) Km 20 to 19 ..... 64/65
5 Historical changes in channel morphology on Elk River, B.C., Km 6 to 5 ..... 68/69
6 Projected climate changes in southwest B.C. due to doubling CO_2 concentrations 71

LIST OF PLATES

1 Construction of spawning channel at Logan Lake (B.C.) in 1991 73
2 Completed spawning channel at Logan Lake (B.C.) 74

LIST OF APPENDICES

A1 Water Quality Requirements for Rainbow Trout 75

A2 Synopsis of Resource Inventory Committee Procedures for Lake Inventory 85

A3 Review of Techniques for Transporting Rainbow Trout 89

A4 Techniques to Mitigate the Effects of Winterkill 93

A5 Review of Aeration Projects Undertaken in B.C. 103

A6 Review of Projects Undertaken to Create Artificial Lakes, Raise Lake Levels or Increase Flushing Rates 111

A7 Review of Projects Undertaken to Create Spawning or Rearing Channels at Lake Inlets or Outlets 121

A8 Review of Projects Undertaken to Create Ecologically Effective Diversion Channels Around Pits, Rock Dumps and Settling or Tailings Ponds 131

ABSTRACT

This study investigated the effectiveness of compensation measures used to recreate rainbow trout habitat or increase stocks in the interior of British Columbia. Identified compensation techniques included stock transplanting, manipulating lake levels and throughflow, creating spawning/rearing channels and constructing "fish friendly" diversion channels.

Our analyses indicate that rainbow trout are amenable to transplanting and have been stocked in about 2,430 B.C. lakes. Aeration projects were found to perform reliably in locations which are readily accessible and have a reliable power supply. Manipulation of lake levels, flow augmentation and the creation of new lakes have all been successfully used to increase fish production or provide recreational fisheries. Augmenting both lake level and throughflow or creating new lakes appeared to be slightly more successful than simply raising the level of an existing lake. The evolving performance as lakes age is generally unknown.

Less than half of the channels that have been constructed or enhanced to provide spawning or rearing habitat have been successful, and many successful sites require pumping, gravel clearing or other maintenance activities on an annual basis. Diversion channels around pits, rock dumps and settling or tailings ponds have proved to be difficult to construct in a manner which provides successful habitat.

Projects undertaken to develop or provide compensatory habitat for rainbow trout need to be designed on the basis of the best available science. The design team should be aware of how well similar projects have previously performed and what factors influenced success or failure. The approval process should include a requirement that monitoring, maintenance and proper evaluation be undertaken regularly over the design life of the project.

RÉSUMÉ

L'étude a porté sur l'efficacité des mesures de compensation visant à rétablir l'habitat ou rétablir les stocks de la truite arc-en-ciel en Colombie-Britannique. Parmi les techniques de compensation identifiées, notons la transplantation, la manipulation du niveau et du débit traversier des lacs, la mise en œuvre de frayères artificielles et de bassins d'alevinage ainsi que la construction de chenaux de dérivation favorables au poisson.

Nos analyses ont révélé que la truite arc-en-ciel peut être transplantée et qu'elle a été ensemencée dans environ 2 430 lacs de la Colombie-Britannique. Les projets d'aération se sont avérés sûrs dans les sites facilement accessibles qui ont une source d'énergie fiable. La manipulation du niveau des lacs, l'augmentation du débit et la création de nouveaux lacs ont contribué à augmenter la production de poisson et à fournir des zones de pêche récréative. L'augmentation du niveau et du débit traversier des lacs et le creusement de nouveaux lacs semble être un peu plus efficace que la seule augmentation du niveau d'un lac existant. L'évolution du rendement des lacs, à mesure que ceux-ci vieillissent, est généralement inconnue.

Moins de la moitié des chenaux construits ou modifiés pour fournir un habitat de fraye ou d'alevinage ont eu les résultats prévus. De plus, dans la plupart des sites fonctionnels, il faut effectuer des travaux d'entretien tous les ans, notamment le pompage et l'extraction de gravier. Les chenaux de dérivation aménagés pour contourner les excavations, les décharges de débris rocheux et les bassins de décantation ou de résidus ne génèrent pas un habitat adéquat.

Les projets visant à établir ou à fournir un habitat compensatoire pour la truite arc-en-ciel doivent être conçus selon les meilleures connaissances scientifiques disponibles. L'équipe chargée de la conception devrait connaître le résultat de projets semblables antérieurs et les facteurs qui ont contribué au succès ou à l'échec de ces projets. Le processus d'approbation devrait entre autres exiger que le projet soit surveillé, entretenu et évalué adéquatement tout au long de sa durée prévue.

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DISCLAIMER

This report is principally based on a literature review and interviews with managers or scientists. The success of various types of fisheries enhancement, compensation or mitigation projects have been evaluated from this information. The reader should, however, be aware that the objective has been to assess the various techniques employed, rather than to comment on the performance of any individual project.

During the course of this work, it became evident that the interests, perspective and background of the people supplying information about a project affected the criteria used to evaluate success and the ratings provided. In some cases, there were differences between ratings given by different individuals for the same project. We have not had the opportunity, nor would it likely be justified, to provide copies of our text to all the people contacted and attempt to settle differences of opinion. We have made an effort to present and interpret the information provided in a consistent and fair manner. However, as we have not had the opportunity to personally inspect the evaluated projects in the field with the people involved, it is likely that some errors in classification have occurred. We apologize in advance if this has caused an unavoidable misrepresentation of the results at any particular site. We again stress that it is the statistical summary and the lessons learned that are important. Data from any individual site was only a means to achieve this objective.

The volume and quality of literature available on each of the topics of interest to this study was variable. In many cases we did not have the resources necessary to undertake a comprehensive analysis. In these circumstances our results are based on a "strategic review" of the identified sources. It is our opinion that a more thorough investigation would not substantially affect our conclusions.

Finally, the conclusions and recommendations in this report are those of the authors and do not necessarily reflect those the Department of Fisheries and Oceans.

1.0 INTRODUCTION

A variety of techniques have been used to create rainbow trout habitat or to increase stocks in the interior of British Columbia. Many of these projects have been undertaken to compensate for the loss of rainbow trout habitat. However, the effectiveness of these techniques has not been systematically reviewed.

The Major Projects Review Unit of the Department of Fisheries and Oceans has therefore commissioned this study to investigate how well various habitat creation or stock enhancement projects have performed and to identify the factors which have influenced success or failure. Identified compensation techniques included stock transplanting, manipulating lake levels and throughflow, creating spawning/rearing channels and constructing "fish friendly" diversion channels. Each of these techniques is discussed and the success rates of completed projects have been summarized on the basis of personal interviews and published or 'grey literature' reports.

The project methodology is described in SECTION 2 and a synopsis of rainbow trout habitat requirements is presented in SECTION 3. The factors which affect the success rates of transplanting rainbow trout into barren lakes are reviewed in SECTION 4. This includes a discussion of both summer and winterkill. Projects undertaken to raise lake levels, augment lake inflow or to create new lakes are reviewed in SECTION 5. Enhancement or construction projects to create spawning/rearing channels are discussed in SECTION 6 and the ability of mine site diversion channels to provide fish habitat is assessed in SECTION 7. The compiled success statistics are summarized and compared in SECTION 8.

A total of eight technical appendices have been prepared. Water quality requirements for rainbow trout are summarized in APPENDIX 1. The BC Government Resource Inventory Committee procedures for lake inventory are reviewed in APPENDIX 2. Techniques for transporting rainbow trout and mitigating the effects of winterkill are discussed in APPENDICES 3 and 4. Aeration projects are reviewed in APPENDIX 5 and projects undertaken to create artificial lakes, raise lake levels or increase flushing rates are described in APPENDIX 6. Spawning or rearing channels are reviewed in APPENDIX 7 and data on mine site diversion channels are compiled in APPENDIX 8.

2.0 METHODOLOGY

This work was to be undertaken on the basis of a literature review, interviews with scientists or managers and on the basis of the principal authors' previous experience.

Completed projects which could provide relevant information were identified through:

i) a review of computer data bases containing information on stream restoration or enhancement projects *(Hartman and Miles, 1995; DFO Fisheries Project Registration System VI.5, 1999 and the Pacific Biological Station Data Base of Fisheries Publications)*;

ii) a subcontract to R.L. & L. Environmental Consultants Ltd. (RL&L) of Edmonton, Alberta to provide a listing of relevant projects in Alberta and eastern British Columbia;

iii) telephone interviews or meetings with provincial and federal government employees;

iv) telephone interviews or meetings with mining company representatives; and

v) a review of relevant scientific journals, government or private publications and books. Journal searches included *Transactions of the American Fisheries Society (1957-1998)* and the *Journal of the Fisheries Research Board/Canadian Journal of Fisheries and Aquatic Sciences (1973 to 1982;1977 to 1998)*.

Dr. Hartman subsequently met with the regional fisheries biologists in Kamloops, Williams Lake and Penticton to review in-house documents and obtain unpublished information.

The information compiled for this project came from a wide variety of sources. Information on project success has been generally developed from interviews with field biologists. In some cases, we received different ratings for the same project. This reflects both a scarcity of formal reports and varying perspectives of the people being interviewed. For example, an artificial lake might be rated as an outstanding success by someone who based their assessment on the ability of the site to support a recreational fishery. However, the project might also be considered to be of limited success if the population was not self-sustaining, the fish were contaminated with metals or the lake provided an unaesthetic environment in which to fish. We have therefore attempted to rate the success of projects according to the respondents objectives. For example, a lake level may have been raised, an aerator operated and spawning gravel introduced. If all these worked well, the project would have been given the highest success rating as its' objectives were achieved. This does not imply that such a system is equivalent to, or equally desirable as, a lake or stream in which fish production is self-sustaining.

The project rating system used in this study was originally developed by *Hartman and Miles (1995)*. In this earlier review, funding did not permit the acquisition of detailed information for each project or the implementation of systematic field studies needed to develop a set of quantifiable criteria for success. Individuals who had completed habitat improvement projects were therefore asked to provide an overall rating for this project using the following classification; complete failure, limited success, successful, or outstanding. Although these are subjective ratings, most participants were personally contacted to discuss the factors which they considered when making this assessment. This allowed a variety of projects to be evaluated in a relatively consistent manner.

The present project faced similar difficulties and the range of projects to be assessed was even more diverse than in *Hartman and Miles (1985)*. The same hierarchical ranking approach and discussions with the respondent was therefore employed to determine how well the project achieved the original objectives. The element of subjectivity in such an evaluation process is recognized. Hartman and Miles

(1995) discussed the desirability of establishing more robust procedures for planning, constructing, maintaining and evaluating projects. However, various constraints prevented such an approach from being undertaken in this study.

As discussed in the "Disclaimer", we have attempted to present the information we received in as accurate a manner as possible. Despite these efforts, some errors in classification could still have occurred. A subsequent study to inspect relevant projects in the field and obtain first hand information would go a long way towards rectifying this deficiency.

3.0 RAINBOW TROUT

3.1 SPECIES DIVERSITY

The species *(Oncorhynchus mykiss)* is represented by an anadromous form, steelhead, and a non-anadromous form, rainbow trout. Rainbow trout are found between Mexico and Bristol Bay in Alaska and on both sides of the Rocky Mountains. A variety of sub-species occur within this wide geographic range. As a result, the size and life histories of rainbow trout are quite variable.

Adult fish sizes in different populations of wild rainbow trout range from 15 cm *(Northcote and Hartman, 1988)* to about 78.5 cm *(Scott and Crossman, 1973)*. There are also three basic life history strategies:

i) they may occur in streams above waterfalls in a non migratory form *(Northcote and Hartman, 1988)*. In this life history pattern, a short section of stream provides the living space for all life stages and activities;

ii) populations may reside in large rivers and spawn within the river or adjacent tributaries *(Ford et al., 1995)*. The migrations of spawning fish in these populations may be short; and

iii) in the most characteristic life history pattern, the fish reside within a lake and spawn in outlet or inlet tributary systems, or both *(Lindsey et al., 1959)*.

Rainbow trout exhibit these three different life history strategies and select different pats of the environment depending on the age and activity of the fish, the season and the time of day. During the spring, summer and early autumn fry occupy the margins of large streams or the margins and riffles of small streams. The fry feed primarily on drifting invertebrates. Fry entering lakes follow the shore and remain in shallow water feeding upon insects and plankton in the littoral zone.

During spring, summer and autumn juvenile trout occupy sheltered pools in streams and large river or occupy deep riffles in small streams. In large rivers, juveniles reside near the shelter of boulders or large woody debris in the channel. At night they may leave the shelter and occupy shallow runs and riffles.

During winter the juveniles move into the stream or river bottom if conditions permit. If they do not hide in the streambed, they will seek out deep cover among boulders or woody debris.

Spawning trout require gravel bottom areas and prefer spawning habitat with cover nearby. However, trout in spawning areas with high fish densities will remain exposed while spawning. Adult trout in streams and rivers occupy the deepest pools and runs. They prefer locations with boulders, woody debris cover or a rippling water surface. In BC interior rivers adult trout, up to 20 cm, may hide deep among boulders or enter the stream bed it if is porous enough. Adult trout use the open water areas of lakes during the day and may move into shallower areas during the night.

All age groups of trout have more specific requirements for water quality, temperature, and flow regime. The adults also have specific requirements for spawning which vary with fish size.

The above information is based on observations made during years of field work by G. Hartman. The life history and habitat requirements of rainbow trout was also reviewed in the report by *Scott and Crossman (1973)*.

3.2 ENVIRONMENTAL REQUIREMENTS

3.2.1 Life History Linkages and Habitat Connections

There are a specific series of habitat requirements for each life history pattern. The life stages are linked one to another and the required habitat must be present to permit existence at each stage and allow movement to the next. Regardless of whether the trout are resident in a stream (and only move a short distance for winter habitat cover or spawning habitat) or whether they reside in a lake (and have lake to stream and return migrations), they require unrestricted movement, appropriate temperatures, food, cover and suitable water quality. Failure to find any of these requirements constitutes environmental impairment and indicates that the system is not a fully-functional ecosystem for trout production.

3.2.2 Water Quality Requirements

Appropriate water quality is critical to the existence of rainbow trout. To a large extent, the requirements are similar at all life stages.

In most natural environments, rainbow trout do not experience detrimental conditions of oxygen, ammonia, pH or heavy metal concentration. However, where there are anthropogenic influences, one or several of these conditions may occur at a detrimental level through either direct contamination or through bio-accumulation. High sediment concentration and water temperature are important factors which may affect production, even in non-impacted systems. Oxygen depletion occurs in many ice-covered lakes during the winter in British Columbia.

A brief review of selected water quality criteria is presented in APPENDIX 1 and this information is summarized on *Table 1*. A number of these water quality factors can interact with each other to increase toxicity by cumulative effects or synergistic processes. The data by *Newcombe and Jensen (1996)* indicate that both concentration and duration are important when assessing the impacts of suspended sediment and similar effects may prove to be important for other contaminants.

3.2.3 Gravel

There are size and quality requirements for rainbow trout spawning. Typical gravel size ranges between 0.4 to 10.0 cm *(Ford et al., 1995)*. However, appropriate gravel sizes depend on the size of the spawning fish. Gravel utilized by spawning fish of 20 to 33 cm in length in Loon Lake, B.C. inlet creek ranged between 0.2 and 10 cm in diameter *(Hartman et al., 1962)*. Kootenay Lake, B.C. rainbow trout, which are up to 80 cm long, utilize larger spawning gravel ranging between 0.5 and 45 cm in diameter. In some sections of the spawning area, fish used patches of coarse gravel comprised of material up to 15 cm in diameter. These patches were interspersed among boulders up to 45 cm in diameter *(Hartman, 1969)*.

Gravel must be permeable enough to permit water movement through it. This is needed for the delivery of oxygen and the removal of metabolic wastes from trout eggs. The survival of steelhead trout embryos increased from 20% at a "mean apparent velocity" of 5 cm/s to 50% at a mean apparent velocity of 100 cm/s *(Coble, 1961)*. Mean apparent velocity was an indicator of the actual water velocity through the gravel. The interstitial spaces in the gravel must also be large enough to permit the emergence of alevins from the gravel. Survival and time to emergence increased with particle size in flow-through incubation units *(Witzel and MacCrimmon, 1981)*. For optimal egg survival and alevin emergence, fine material ≤2 mm in diameter should make up no more than 5% of the spawning substrate *(Ford et al., 1995)*.

3.2.4 Stream Bed Stability

The stream bed in the areas used by spawning fish must be stable, particularly during the period while eggs are incubating. A measure of scour during the incubation period provided the most successful explanation of the inter-annual variation in egg-to-fry mortality of coho salmon in Carnation Creek, B.C. *(Holtby and Healey, 1986; Holtby and Scrivener, 1989)*. Coho salmon eggs, which are deposited during the fall, may be somewhat more likely to be subject to conditions of stream bed instability than those of spring spawners such as rainbow trout. However, interior British Columbia streams can experience sizeable snowmelt freshets during May or June and the importance of stream bed stability to spawning trout applies in such situations.

3.2.5 Flow Regime and Water Depth

The depth and water velocity required by rainbow trout increases with the size of the spawners. The preferred water velocity for spawning rainbow trout is 30 to 90 cm/s *(Ford et al, 1995)*. However, a water velocity range of 75 to 90 cm/s is very high for trout <35 cm long. The large Gerrard trout spawned in water velocities >90 cm/s *(Hartman, 1969)*. The preferred depth for spawning ranges between 15 and 250 cm *(Ford et al., 1995)*. However, large fish, 75 to 80 cm in length, prefer depths of 30 cm or greater *(Hartman and Galbraith, 1970)*.

When considering flow requirements, fish managers are frequently principally concerned with spawning needs. However, flow regimes must also provide water conditions that clean and renew spawning gravel, provide aquatic rearing habitat, etc. (for example see *Poff and Ward, 1989* or *Richter et al., 1997*).

Rainbow trout can also actively alter instream conditions. For example, the combination of moderately high spring flows and trout spawning activity created "dune-like" structures which improved the spawning habitat at Gerrard, north of Kootenay Lake, British Columbia *(Hartman and Galbraith, 1970)*.

High flows which disturb gravel may have negative effects on egg-to-fry survival. However, over the longer term these events play an important role in reconditioning spawning habitat and creating new channel structure.

4.0 TRANSPLANTING RAINBOW TROUT TO BARREN LAKES

It is common knowledge that rainbow trout are exceptionally adaptable and can be readily introduced to barren environments if conditions are suitable. As a consequence, there has been a long history of moving rainbow trout around British Columbia. The records of the early B.C. provincial transplanting activities are sketchy. When *Northcote and Hartman (1988)* did field reconnaissance to locate 'native' populations of headwater trout, they found that numerous stream dwelling populations had been established during the early decades of the century and their introductions were undocumented. Many of the records that were made were poorly kept or lost. For example, several notebooks full of B.C. provincial transplant information were lost or destroyed when Jimmy Robinson, one of the pioneering B.C. fisheries field people, died in about 1950.

Since the 1930-40 period, rainbow trout have been transplanted into hundreds of lakes in British Columbia through the stocking programs of the provincial hatcheries. In B.C. MOELP Region 3 (Kamloops) approximately 100 previously barren lakes were stocked with rainbow trout during J. Cartwright's period of employment. About 100 more were stocked during B. Chan's employment *(J. Cartwright and B. Chan, pers. comm.)* About 3,334 lakes in British Columbia have been stocked with fish. Of these about 2,430 have been stocked with rainbow trout *(D. Peterson, pers. comm.)*.

Fish from existing lake stocks may be introduced into barren lakes by:

i) incubating eggs collected in inlet or outlet streams. This may be undertaken by simply burying the eggs in a suitable location or by placing them in incubation containers;

ii) incubating collected eggs in a hatchery and transplanting fry; and

iii) transplanting fry from one lake to another.

Options ii) and iii) require that fish be handled and transported and this must be undertaken in an appropriate manner as described in APPENDIX 3.

If the lake that is to receive the fish only has outlet spawning habitat, the fish put into it should be progeny from outlet spawners. If direct transplants of fry or larger fish are to be made from another lake, such fish should be outlet stream progeny. In these circumstances only a few hundred fish may be available at a time. If the fish can not be transported immediately, consideration must be given to holding them under as low stress levels as possible. This may require special facilities at the lake from which the fish are taken.
Transplanted fish must be unloaded adjacent to an area in which the water temperatures are within a few degrees of the water in which the fish arrive. If the water in which the fish are transported has been supersaturated with oxygen, they must be given a chance to become accustomed to the lower oxygen levels of the receiving water. Sudden transfer from water that is highly saturated with oxygen to water with natural saturation levels will stress the fish *(Wedemeyer, 1996)*.

4.1 QUANTIFICATION OF BRITISH COLUMBIA PROVINCIAL LAKE HABITAT

The Resource Inventory Committee of the B.C. Government has prepared standardized procedures for the quantification of lake habitats. Relevant reports include:

> Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures Ver 1.1. *(Ministry of Fisheries, 1998a)*;

Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Data Forms and User Notes. *(Ministry of Fisheries. 1998b.)*;

Standards for Fish and Fish Habitat Maps. *(Ministry of Fisheries, 1998c)*; and

Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Lake Survey Form Field Guide. *(Ministry of Fisheries, 1999a)*.

A brief description of these inventory procedures is presented in APPENDIX 2.

These B.C. provincial procedures provide detailed directions for carrying out lake inventories and provide a useful guide for assessing lake habitat. However, the procedures do not compile all the information necessary to assess how much habitat would be developed if lake levels were raised to provide more habitat. Nor do the procedures adequately assess the potential for winterkill. Specific deficiencies from the perspective of raising lake levels include:

i) the procedures do not provide information that would allow a manager to determine the actual percent increase of littoral area that would result from raising the level of a lake by a given amount;

ii) the collected data might indicate the amount of shore cover resulting from an elevated lake level but the nature of shore cover that would be provided is not described. [However, we are not certain that enough is known about the winter behaviour of fish to determine how they would use shore cover in lakes];

iii) the inventory method does not provide the information needed to assess the spawning area available in the shore zone. This is not critical for rainbow trout but is important for kokanee and lake trout;

iv) the maximum water level is not a meaningful piece of information unless taken at low water. Although the amount of seasonal variation in lake level affects the ecology of a lake, maximum level measurements do not indicate this range;

v) the ratio of drainage area to lake area is an important indicator of nutrient dynamics and status. However, the survey system does not incorporate precipitation or hydrological information which could better define the lake characteristics. Similar ratios of drainage area to lake area will have different implications in coastal and interior dry-belt areas;

vi) assessment of species composition and population size from one year's sampling may be misleading. Year class strength of many species varies from year to year. More reliable sampling would require multi-year data; and

vii) lakes may vary from year to year in regard to temperature, plankton blooms and oxygen profiles. The behaviour and distribution of fish may vary as well. For example, in Nicola Lake, B.C. the pattern of diel vertical migration of two species reversed in two years *(G. Hartman observation)*.

4.2 ASSESSMENT OF PRODUCTIVE CAPABILITY

4.2.1 Introduction

The Department of Fisheries and Oceans (DFO) may seek replacement of fish habitat which is severely disturbed or destroyed by industrial projects under the "no net loss" guiding principal *(DFO, 1986)*. DFO may request a greater area of replacement habitat than the area lost depending upon the nature of the loss and the estimated fish productive capacity. Therefore, DFO requires a reliable assessment of the productive capacity lost in a project. DFO may also be interested in determining the increase in productive capacity that might be obtained by increasing the level of a lake or reservoir. There are various means of determining habitat productive capacity. Some of the inventory and habitat capability assessment methods dealt with in this paper may not be designed specifically for the purposes of determining replacement ratios for lost habitat and productive capacity. However, in the document issued by the *Ministry of Fisheries (1998a)*, the introduction states that:

> ***"this inventory is intended to provide information regarding fish species characteristics, distributions and relative abundance, as well as stream reach and lake biophysical data for interpretation of habitat sensitivity and capability for fish production".***

It also states that 'the inventory provides information vital for the protection and management of fish species and populations'. Although there may be an emphasis on applications in connection with the B.C. Forest Practices Code, this does not exclude use of the information in regard to other habitat issues or within the context of DFO's Policy for the Management of Fish Habitat *(DFO, 1986)*. For these reasons the methodology recommended by *Ministry of Fisheries (1998a)* has been reviewed and commented upon. The RIC Standards and lake productivity models were also reviewed as DFO may wish to consider the effectiveness of such methods for determining what mitigation or compensation value to expect from a particular habitat modification.

The interpretation of lake inventory information and the preparation of productive capacity projections is a difficult undertaking, particularly if the results are to be used by managers to determine area-based habitat replacement ratios.

The techniques for quantification of lake habitat *(Ministry of Fisheries, 1998a)* describe methods to assess the key variables that might affect lake productivity. However, there is a large step between documenting an array of lake features and quantification of the productive capacity of a lake. The "morphoedaphic index", or MEI, can be developed from lake inventory data and predicts an expected range of production for a particular type of lake. The MEI is obtained by dividing the total dissolved solid concentration (TDS in ppm) by the mean depth in feet *(Ryder, 1965)*. Production increases with increase in the MEI but the relationship is not linear. In addition, production increases with decreased latitude *(Figure 1)*. The actual data points may be scattered such that production may have threefold variation about the curves (see data in *Ryder, 1965*). The species composition in catches varies and the MEI does not specify the potential production of a specific kind of fish.

Production of fish in a lake is the result of a configuration of dynamic and interacting conditions and processes. If modelled production projections from the MEI are to be refined, it is necessary to obtain inventory data that show year round patterns of changes in features such as temperature, oxygen profiles, lake transparency, water level and water quality. These conditions interact through time to moderate production. In addition to this, the quality of the reproduction and rearing environment will affect the production of the lake in a natural, self-sustaining system. The lake and its tributaries are connected. It is not meaningful to consider production in either, independently. Finally, the composition of the fish fauna will affect the quantity of production of the species that people use.

The B.C. RIC lake and stream inventories do not provide a basis for estimating, in advance, the production that might be obtained from "replacement habitat". It should also be recognized that if the replacement habitat is suitable, it may have already been stocked or colonized naturally.

We do not believe that the British Columbia inventory provides a particularly sensitive basis for determining compensation ratios. This arises from the number of ways in which estimated replacement area requirements might become un-coupled from static inventory data.

4.3 HABITAT SUITABILITY INDEX

The habitat suitability index (HSI) is a numerical index that represents the ability of a particular piece of habitat to support a species of fish. There are five steps in establishing the HSI:

i) a series of variables that represent different features of the fish habitat are chosen;

ii) these variables are used to establish 'suitability' curves for each feature;

iii) through the use of the suitability curves, each habitat feature can be given a suitability index (SI);

iv) the suitability indices are combined to give an overall SI for each life stage of the species; and

v) the SI values for all life stages are added to produce the HSI for the species.

This model assumes a linear relationship between the HSI and the carrying capacity for the species *(Persons and Bulkley, 1984)*. Individual SI curves for rainbow trout have been established *(Raleigh et al., 1984)*. Procedures employing the values of *Raleigh et al. (1984)* have been used to establish the expected conditions or value of habitat after changes in stream level.

There may be some merit in having the SI curves to describe habitat features for rainbow trout. However, using combinations of these curves in a HSI to assess impacts is not reliable because changes in the HSI may not be accurately reflected in standing crop *(Terrell and Nickum, 1984)*. *Stoneman et al. (1996)* used existing HSI models to predict trout biomass in southern Ontario streams. The models were "poor predictors".

4.4 WINTERKILL

4.4.1 Introduction

Many lakes in British Columbia are devoid of fish because of "winterkill". Fish begin to die off when the dissolved oxygen decreases to lethal levels. This typically occurs during ice cover conditions in winter. Depressed oxygen concentrations can also occur during the summer; the factors responsible for "summerkill" will be described subsequently in SECTION 4.5.

In barren lakes the limnological conditions which can produce winterkill must be well understood before management decisions are taken, expenditures for transplanting fish are made and public expectation is established. These conditions, and the degree to which managers understand them, will determine the overall success of a transplant program.

Winterkill is common among shallow eutrophic lakes that are subject to cold temperatures and prolonged ice and snow cover. For example, as many as half of Wisconsin's 14,000 lakes are subject to winterkill. An average of 125 recorded winterkills occurred annually between 1955 and 1982 *(Fast, 1994)*. Of the 1,814 lakes in the Thompson/Nicola Plateau, British Columbia, which are under 500 ha, 15% are rated as having a high risk for winterkill *(Ashley et al., 1992)*.

4.4.2 Processes Responsible for Winterkill

The problems of winterkill are caused by a sequence of related events. These may include:

i) the stratification of the lake during summer and depletion of oxygen in the deep layer of water;

ii) the incomplete mixing of the deep, oxygen-poor water during autumn so that overall oxygen concentrations are low in the lake at the time of ice formation;

iii) the reduction of oxygen levels under the ice by decomposition of organic material. The greater the amount of organic material in the water column and sediments, the greater the risk of winterkill; and

iv) decreased winter photosynthesis and oxygen production due to an ice and snow layer on the lake.

Temperature stratification of water in a lake is the result of the behaviour of light and the properties of water. As solar radiation passes down through water it disappears exponentially and the heating wavelengths are absorbed rapidly *(Cole, 1983)*. This results in the upper water becoming warmed and less dense. If the lake is not mixed by wind action, a sharp temperature gradient may become established with a layer of relatively warm water above a transition layer and a layer of cooler water below. The three layers are commonly referred to as the epilimnion, thermocline and hypolimnion.

As the lake cools during autumn, the water temperature gradient in the thermocline may become less sharp and winds may mix the water from top to bottom making it uniform in temperature.

Water has a maximum density at about 4°C. So, as the lake cools during the autumn and early winter, the overall temperature decreases to 4°C. With continued heat loss, the layer of water near the surface decreases to less than 4°C and, being less dense, remains near the surface. When ice, which is less dense than liquid water forms, it also remains at the surface.

Winterkill problems originate in large measure with the production of organic materials in the zones of the lake where light penetrates. The organic material that is not consumed or recycled settles to the bottom where it may collect and decompose. In shallow and productive lakes, decomposition may reduce oxygen levels in the hypolimnion to anoxic conditions.

Reduced light conditions during periods of ice and snow cover prevent photosynthesis and oxygen production but allow decomposition to proceed to the extent that all oxygen in the water is consumed. Fish kills may also occur during spring breakup when small amounts of oxygen that were at the surface become mixed with a larger volume of de-oxygenated water.

4.4.3 Factors Influencing the Incidence of Winterkill

Collectively, the lakes that are most commonly subject to winterkill are eutrophic, prone to stratification and are ice or snow covered from early winter to spring *(Greenbank, 1945, Halsey, 1968; Patriarche and Merna, 1970; Summerfelt et al., 1980; Fast, 1994)*. In addition to these conditions, there are a number of more specific features that cause lakes to be prone to winterkill. While elements involved in winterkill are discussed separately, it is important to recognize that these elements do not occur or operate in isolation. In assessing the potential of any lake for summer- or winterkill, all of the six features listed below should be recognized and considered. The relative significance of each will vary from one lake to the next.

Factors which influence the occurrence of winterkill include:

i) basin morphometry;
ii) lake bottom sediment type;
iii) ratio of lake bottom sediment area to lake volume;
iv) amount of dissolved oxygen in the lake at the time of freeze-up;
v) ice/snow conditions and under-ice photosynthesis; and
vi) trophic status.

Each of these are discussed in more detail below.

4.4.3.1 Basin Morphometry: Lakes that are shallow and oriented so that the prevailing winds have maximum fetch are less prone to winterkill than those with deep basins that are not exposed to wind action. The condition of 'meromixis' in which lakes become chemically and thermally stratified may result in large part from the morphometric characteristics of the lakes *(Northcote and Halsey 1969)*. For example, *Halsey (1968)*, in a study of three lakes in the southern interior of British Columbia, found that Courtney Lake, which had a mean depth of 4.9 m and an average daily wind velocity of 199 cm/s, had no record of winterkill. In contrast, Marquette and Corbett Lakes, which had relatively deep basins and were located in topography that reduced average wind velocities, were prone to winterkill. *Ashley (1983)* and *Halsey and MacDonald (1971)* indicate that Black Lake and Yellow Lake, located in southern central British Columbia, have steep sides, relatively deep basins and the long axis of the lakes are perpendicular to the prevailing wind. Both lakes are subject to winterkill.

4.4.3.2 Lake Bottom Sediment Type: Lakes with muck or silt bottoms and a high percentage of the shoreline in emergent and/or submerged vegetation have a higher probability of experiencing fish kills during winter *(Fast, 1994)*. These conditions contribute to the high biological oxygen demand that leads to winterkill. For example, the bottom sediments of winterkill lakes in South Dakota typically consist of *"an organic ooze, smelling richly of hydrogen sulfide" (Nickum, 1970)*. In the Sandhill region of Nebraska, the bottom sediments of lakes that had fish kills in 3 out of 10 years were 60% "muck" *(Schoenecker, 1970)*.

4.4.3.3 Ratio of Lake Bottom Sediment Area to Lake Volume: Attempts to relate morphometric variables or indices of trophic status to oxygen depletion rates have only been partly successful *(Mathias and Barica, 1980)* as the potential for fish kill is also related to the ratio of the sediment area in the lake bottom and the volume of the lake.

Oxygen depletion under an ice cover depends upon the total biological oxygen demand (TBOD), i.e. the water column biological oxygen demand (WBOD) and the bottom sediment biological oxygen demand (SBOD), *(Cross and Summerfelt, 1987)*. SBOD is an important determinant of the oxygen depletion rate under ice. It may be substantially higher than the WBOD. For example *Cross and Summerfelt (1987)* found that SBOD was about 14 times greater than WBOD in two small lakes in Iowa. *Mathias and*

Barica (1980) found that sediments in eutrophic lakes consumed oxygen about three times faster than those in oligotrophic lakes but that water column rates of depletion were about the same in the two types of lakes. SBOD is dependent upon the aerobic oxidation of organic material, by bacteria *(Cross and Summerfelt, 1987)* and the oxidation of reduced metals (Fe and Mn), *(Ashley, 1983)*.

Winter rates of oxygen depletion (in $g/m^3/d$) have been shown to decrease asymptotically with mean depth as illustrated on *Figure 2 (from Mathias and Barica, 1980)*. Oxygen depletion rates also increase with the ratio of sediment area to lake volume. As illustrated on *Figure 3*, the rate of oxygen depletion in eutrophic lakes becomes progressively greater than that in oligotropic lakes as the ratio of sediment area to lake volume increases.

4.4.3.4 Amount of Dissolved Oxygen in the Lake at the Time of Freeze-Up: The total amount of oxygen in a lake at the time of ice formation may be determined by a number of factors. Basin shape and wind action are critical. For example, the maximum depth of Courtney Lake, B.C. 17 m, was slightly less than that of Corbett Lake, B.C. while its maximum effective length, 946 m, was almost four times greater *(Halsey, 1968)*. Field studies indicate that Courtney Lake, was less stratified and more fully saturated with oxygen than Corbett Lake.

The location of the thermocline and the distribution of oxygen in a lake affects the amount of stored oxygen that a lake carries into the winter. In this sense, the relative volumes of the epilimnion and hypolimnion are critical. A sharply stratified lake with a relatively large, anoxic, hypolimnion volume will mix and carry a lower reserve of oxygen into the winter period than would the same lake if the oxygenated epilimnion volume was large.

The depth of the euphotic zone and consequent volume of the lake available for photosynthesis may also influence the size of the oxygen reserve at freeze-up.

4.4.3.5 Ice/Snow Conditions and Under-Ice Photosynthesis: Photosynthesis under ice by phytoplankton and macrophytes can add oxygen to the water even though winter days may be short and the light intensity low. Some species of plants are shade-adapted and may function under low light intensities *(Fast, 1994)*.

Deep snow and cloudy ice is a critical factor contributing to reduced photosynthesis and depletion of oxygen during the winter. For example, in one study light penetration through 37 cm of ice and 10 cm of snow was reduced to <0.5% of the incident level. Another study showed that 41 cm of clear ice reduced incident light by 54% but the addition of 13 cm of snow reduced it to <1%. In Ray's Lake, Minnesota 2.6% of incident light penetrated 8 cm of snow plus 36 cm of translucent ice. Forty percent of the light penetrated the ice alone. At a later date, 10% of incident light penetrated 6 cm of 'corn' snow plus 43 cm of translucent ice *(all examples from Fast, 1994)*.

4.4.3.6 Trophic Status: Lakes that are subject to fish kills are characteristically eutrophic, *(Puke, 1949; Halsey, 1968; Halsey and Galbraith, 1971; Fast, 1973a; Fast et al., 1975; Mathais and Barica, 1980; Ashley, 1983; Summerfelt, 1983; Summerfelt and Cross, 1983; Bandow, 1986; Soltero et al., 1994;)*. Winterkills of fish occur in lakes in which community respiration is high and some natural event inhibits photosynthesis, or causes a rapid increase in oxygen demand, or both *(Summerfelt et al., 1980)*. For example, dense blooms of algae (Aphanezomenon and Anabaena), high surface temperatures and sharp thermal stratification can lead to hypolimnetic oxygen depletion and fish kills *(Ashley et al., 1992)*.

4.4.4 Review of Previous British Columbia Provincial Aeration Projects

A variety of techniques have been used to prevent winterkill. These date back at least as far as 1929 *(Puke, 1949)*. As discussed in APPENDIX 4, early *ad hoc* techniques have been replaced with specialized aeration equipment during the last two decades. The degree of success has improved dramatically and aeration equipment is now commonly used in British Columbia to successfully reduce or eliminate winterkill [APPENDIX 5].

Project success is summarized on *Table 2* on the basis of subjective assessments made by British Columbia regional staff. The fourfold classification system is the same as that used in *Hartman and Miles (1995)*. The success rates for aeration projects are shown in the following box summary:

B.C. SUCCESS RATE	NO. OF PROJECTS	%	
Failure	4	16	20
Limited Success	1	4	
Moderate Success	2	8	80
Outstanding Success	18	72	
TOTAL # OF PROJECTS	25		

Eighty per cent of the projects were of moderate or outstanding success. This indicates that lake aeration can be undertaken successfully if conditions are suitable and adequate funding is available.

4.4.5 Design of British Columbia Provincial Aeration Projects

The single most important requirement for success in aeration projects is a good understanding of the lake's limnology. Answers to the following questions, listed by *Fast (1994)*, will improve understanding and increase the chances of success for aeration projects:

i) how often does the lake winterkill?
ii) what percentage of the lake's water volume is ice-bound each winter?
iii) what are the lake's areas and water volumes within each depth interval?
iv) what is the average "chlorophyll a" value in the lake during summer?
v) what is the range of oxygen depletion (mg O_2/L/week) during the period of ice cover?
vi) what is the usual duration of ice and snow cover?
vii) are there dense beds of aquatic plants and, if so, what area of the lake do they cover?
viii) does the lake typically reach 100% O_2 saturation each fall prior to ice cover formation? and
ix) what monetary value is placed on preventing winterkill?

We must add other questions that would affect the logistics of aeration projects and influence the decision with regard to whether it should be done:

i) what is the access to the lake during the period when aeration equipment would operate?
ii) what is the availability of power?
iii) what other uses are there for the lake during the period of operation of the equipment?
iv) if aeration is to provide part of the compensation for loss of a natural, self-sustaining, lake, what are the arrangements for maintenance of equipment in perpetuity? and
v) are there aesthetic, social and legal considerations regarding the operation of aeration equipment?

These five points touch on issues that should be considered when compensation projects are being reviewed.

The general information that *Fast (1994)* regarded as being of primary importance provides some guidance regarding expectation of oxygen consumption, however, geographic conditions will influence the risk of winterkill in lakes.

Local fisheries managers may know whether or not winterkill occurs in a particular lake. Winter limnological surveys by helicopter provided a rapid and useful first appraisal of the risk of winterkill in the Caribou region of British Columbia *(Lirette and Chapman 1993)*. They surveyed 303 lakes and classed them as excellent, good, fair or poor if oxygen concentrations were >7, 3 to 7, 1 to 3 or <1 mg/L, respectively. This type of survey (which cost $18,000) provided a useful guide for stocking trout. However, it did not explain why different lakes had different oxygen concentrations.

An understanding of the conditions that determine the rate of oxygen depletion will provide the information needed to determine the type and capacity of aeration equipment that might be required. As indicated in *Fast (1994)*, the required aeration capacity (as indicated by the horse power rating of the equipment) increases with lake area. Equipment employed has ranged from about 5 HP on 2 ha lakes to about 20 HP on 10 ha lakes (i.e. 2 to 2.5 HP/ha). Most successful British Columbia winterkill prevention projects have had large aeration capacities relative to the size of the lake. Many have failed because pump input capacities were too small. In lakes where the oxygen concentrations have fallen to < 3 mg/L, aeration with under-capacity systems may worsen the situation. The injection of oxygen, at a low rate, may increase the rate of oxygen consumption and exacerbate the winterkill conditions because the presence of oxygen may accelerate the rate of oxidation of materials in the sediment. This problem will be most serious if the bottom sediments are stirred by aeration. Aeration has to provide enough air to oxidize the WBOD and the SBOD. If the WBOD and SBOD are both reduced before ice cover forms, oxygen depletion rates under the ice will be lower and the chances of winterkill reduced.

In shallow lakes, e.g. mean depth 2 m, the formation of ice could reduce the water volume of the lake and the stored heat energy by 25%. If a large percentage of a lake's volume is tied up as ice, there may be insufficient heat in the remaining water to melt the ice and create an opening adequate enough for diffusion of sufficient air. In addition to this, there are other considerations about aeration projects.

Ashley and Hall (1990) cited two technical difficulties that are associated with hypolimnetic aeration:

i) estimating the oxygen consumption of the water body; and
ii) estimating the oxygen input capacities of the aeration system used.

They indicated that more research is needed to quantify the amount of oxygen that aeration systems can provide. The effectiveness of an aeration system will depend upon the size of the pump, the morphometry of the lake and the depth at which air may be injected. The rate of oxygen uptake increases with hydrostatic pressure and is also controlled by the size of bubbles and their rate of assent. Lake size and morphometry will determine the depth of placement and the number and locations of aeration units.

4.4.6 Stocking Winterkill Lakes

There are strains of trout that fill special stocking needs in lakes subject to winterkill. For example, it may be desirable to stock strains of fish that are not wanted or needed in the hatchery system.

Graded large trout, most of which would otherwise mature precociously, might fill special needs for stocking winterkill lakes. *Tsumura et al., (1987)* and *Tsumura and Blann (1988)* recommended stocking of large, graded fish into winterkill lakes to reduce the number of precocious males in the hatchery system and to produce fish large enough to be caught one year after stocking. Other strains of fish might also be selected. For example, there were large differences in catch, 43.4 to 93.2% in the first few days among five strains of rainbow trout tested in Virginia streams *(Fay and Pardue, 1986)*. The percent harvest among three strains of cutthroat trout, tested in ponds in Montana, ranged from 11.2 to 51.9% during the first 10 weeks of fishing *(Dwyer, 1990)*. More rainbow trout, genetically selected for fast growth, were caught per unit of angling effort than was the case for non-selected fish *(Brauhn and Kincaid, 1982)*. *Hume and Tsumura (1992)* concluded that fast-growing, early-maturing 'Premier Lake' trout were more suited to a high-intensity fishery than were slow-growing, late-maturing trout.

4.5 SUMMERKILL

Summer fish kills are frequently caused by the sudden collapse of algal blooms followed by the decomposition of dead algal cells. Lake characteristics identified by *Barica (1975)* which are associated with a high risk of summer fish kills include:

i) low Secchi disc readings <0.4 m and high chlorophyll a levels >100 µg/L *(Barica, 1975)*. Maximum chlorophyll a concentrations >100 µg/L and maximum NH_3-N >1,000 µg/L; and

ii) maximum chlorophyll a concentration >100µg/L and specific conductance >800 µmho/cm.

The above criteria were developed for prairie lakes and ponds which had water depths of 1.0 to 3.9 m. British Columbia lakes, which could be of concern regarding summerkill, may not have parameters within the above ranges. However, characteristics such as high chlorophyll a levels, high phosphorous concentrations, high conductivity or a reduced inflow or outflow of water are likely to be associated with an elevated risk of summer fish kills.

4.6 CONCLUSIONS

1: Rainbow trout are exceptionally adaptable and can be readily introduced to barren environments if conditions are suitable;

2: The British Columbia Resource Inventory Committee procedures for lake inventory provide a systematic basis for collecting descriptive information. This information provides an initial basis for assessing the potential benefits of fish stocking or determining the likelihood of winterkill. However, more detailed surveys, undertaken at representative periods of the year, are needed to provide the information needed to quantitatively assess lake suitability for stock transplanting, the potential for winterkill or the feasibility of successful lake aeration;

3: The productive capacity of a lake may be estimated in many ways. One empirical method used to determine fish yield is the morphoedaphic index (MEI). It is defined as the total dissolved solids (TDS) in parts per million (ppm) divided by the mean depth in feet. Some limitations of this yield estimator have been described in SECTION 5.1, however, the science of estimating production is improving as other correlates of production are being studied and reported.

4: Predicting the potential for winterkill requires a detailed knowledge of the physical, biological and limnological conditions within a lake. Important factors include:

i) basin morphometry;
ii) lake bottom sediment type;
iii) ratio of lake bottom sediment area to lake volume;
iv) amount of dissolved oxygen in the lake at the time of freeze-up;
v) ice/snow conditions and under-ice photosynthesis; and
vi) trophic status;

5: Aeration has been used successfully at 20 sites within British Columbia to prevent winterkill. This is an 80% success rate and indicates that aeration is a feasible technology if conditions are suitable and adequate funding is available;

6: Aeration may cause changes to benthic fauna and the quality of fishing. These may result in increased property values and the creation of public expectations which may make it difficult to stop aeration. It may also result in legal liabilities by creating openings in the winter ice cover;

7: Aeration (and the intensive management that it requires) is more appropriate for intensive fisheries near population centers than remote or wilderness sites. Furthermore the long-term success of aerated lake projects may be compromised by the invasion of non-game fish. This has occurred in several locations including: Dewar, Irish, Yellow and Skulow Lakes. The impact of this in Dewar Lake, for example, has been a substantial decline in the growth rate of stocked rainbow trout and a corresponding decline in angler use of the lake. These effects may change the success rating of the project *(M. Lirette, Pers. comm.)*; and

8: Summer fish kills are frequently caused by the sudden collapse of algal blooms followed by the decomposition of dead algal cells. Characteristics such as high chlorophyll a levels, high phosphorous concentrations, high conductivity or reduced inflows or outflows of water either indicate its likelihood or increase the risk of summerkill.

5.0 RAISING LAKE LEVELS, AUGMENTING LAKE INFLOW OR CREATING NEW LAKES

Lacustrine fish habitat can be provided by constructing new lakes. Existing habitat can also be enhanced by raising water levels or increasing the inflow to a lake or reservoir.

Open-pit coal mines in Alberta, which fill with surface and/or groundwater provide lacustrine habitat. Existing habitat, which may be of low quality, can be enhanced by raising water levels or increasing the flow through it. These types of habitat may not be 'natural lake ecosystems' however they can provide trout fishing in a lake-like setting.

New lakes, or lakes with increased water levels or inflows, have been commonly created for hydroelectric or irrigation reservoirs. These projects are generally large in size and water levels may fluctuate due to seasonal draw-down for hydroelectric or irrigation water demands. Smaller lakes or reservoirs have been developed for waterfowl or fish production and these projects tend to have less variable water levels. A number of recent projects have involved converting industrial reservoirs, such as tailing ponds or end pit lakes generated by coal mining activities, into fish and wildlife habitat.

Much of our understanding of the effects of increased water levels in lakes is based on experience with hydroelectric projects because impact assessment and evaluation has been required by the regulatory agencies . At present there are an estimated 400 hydroelectric projects in Canada affecting over 200 river, lake and stream systems *(Northcote, in press)*. Many of these projects are large and every province except Prince Edward Island has reservoirs exceeding 100 million m^3 in total storage capacity. Depending upon use and location, water levels in these reservoirs may fluctuate from 2 to >30m.

Reservoirs are an important part of the B.C. landscape. There are about 2,600 dams in the province. Of this total, 168 are 'major' dams over 9 m high *(B. Bugslag, pers. comm.)*. Large numbers of dams occur in some areas. *C. Beeson (pers. comm.)* indicates that there are over 450 reservoirs in the Kamloops Region and over 250 in the Okanagan. The number of these reservoirs that support fish populations is not known, however, the large reservoirs (e.g. over 9 m depth) should contain fish. A number of the small aerated reservoirs also support fish.

5.1 LITERATURE REVIEW

5.1.1 Indices of Productivity

The literature dealing with fish productivity is extensive, complex and sometimes contradictory. This may be partly explained as earlier literature sought to find empirical relationships between yield and physical features of lakes and more recent literature has sought to assess actual production processes with precision.

Productivity may refer to the production of phytoplankton, zooplankton, fish, or the combination of all. In one definition, production of fish refers to the elaboration of new biomass from the standing stock *(Leach et al., 1987)*. The term production, when applied to fish, may refer to the entire fish community *(Downing and Plante, 1993)* or may imply the amount that is caught (yield). The types of models used in regard to 'productivity' depend upon whether people were attempting to produce empirically derived estimates of fish yield or attempting to measure total fish-community production. *Ryder (1965)* regarded yield as a reliable estimator of fish production. *Leach et al. (1987)* described the MEI as the best overall estimator of fish yield in the upper Great Lakes. The use of yield data in the development of production indicators is compromised because yield may depend upon such variables as fishing effort and distance travelled to fish.

In some situations the MEI may not estimate the production of fish. Estimates of biological production of the total fish community in 22 lakes from a wide geographic area were not correlated with the MEI *(Downing et al., 1990)*. They found that total fish community production was correlated most strongly with primary production, fish biomass or total phosphorus.

Many workers have utilized information on physical, chemical or biological features, or a combination of them, to estimate potential production in lakes. For example, *Rawson (1951 and 1952)* recognized the relationship between TDS, mean depth and fish production. *Northcote and Larkin (1956)* demonstrated a positive relationship between TDS and quantities of plankton in 100 British Columbia lakes. *Ryder (1965)* demonstrated a positive relationship between fish production and MEI occurred in 34 Canadian lakes.

In some situations TDS seemed to play a dominant role in determining fish production *(Donald and Anderson, 1982)*. TDS explained 41% of the differences in weight among 2 year old trout in lakes in western North America. However, *Downing et al. (1990)* found no significant relationship between TDS and fish production in their review. Stocking density explained 20 to 30% of the differences in weight and mean depth accounted for 3 to 7% of the difference *(Donald and Anderson, 1982)*.

The temperature regime in lakes also affects fish production. One of the criteria for use of the MEI was that the lakes investigated must come from an area with a homogeneous climate. *Ryder et al. (1974)* and *Schlesinger and Regier (1982)* showed that yield and/or biomass increased at lower latitudes *(see Figure 1)*. Use of the MEI was discussed in a number of papers in a special section of the Transactions of the American Fisheries Society *(Rigler 1982; Jenkins 1982; Schelsinger and Regier 1982; Youngs and Heimbuch 1982; Ryder 1982; Oglesby 1982 and Kerr 1982)*. *Ryder (1982)* suggested that yield estimations might be made at three levels:

i) global level – area and temperature assume major importance;

ii) regional level – nutrients and mean depth are critical and area and temperature are held constant; and

iii) infra-regional level – nutrients or mean depth alone may be used as a fish estimator if the other is held constant.

The third point is most relevant when evaluating conditions in lakes within uniform geographic regions of British Columbia.

5.1.2 Importance of Basin Morphometry

Lake morphometry, specifically the amount of littoral area, affects both the risk of winterkill and the potential productivity of the lake. These opposing interests are evident in Kilpoola Lake which is located 6 km west of Osoyoos, B.C. *Northcote (1980)* indicated that 75% of the bottom area and 72% of the lake volume was above 4 m. The lake supports populations of phytoplankton, zooplankton and benthos. However, it has low oxygen concentrations during summer below the 5 m level. It is also at high risk of having fish kills during winter *(Northcote, 1980)*.

Shoal or littoral areas, and the vegetation in them, play a number of roles in a lake ecosystem. They produce oxygen during periods of sun-light and growth and may contribute to eutrophication. On the other hand, they contribute substantially to oxygen reduction during darkness in warm periods and periods of heavy ice and snow cover in the winter. These same environments may also provide important habitat for fish and thus contribute to production. Vegetated littoral zones in Hamilton Harbor,

Bay of Quinte and three bays in the Georgian Bay region, had higher fish densities and greater species richness than non-vegetated sites *(Randall et al., 1996)*. There are, however, littoral zone areas that are productive for fish but have scanty vegetation *(Welch, 1952)*.

Where lakes are being constructed, designers should consider the effects of different lake morphologies on the quality of the lake. In the littoral zone of two small man-made lakes on Pender Island, coastal British Columbia, the bottom profiles influenced the degree of weed growth and eutrophication *(Northcote, 1980)*. Buck Lake, which was slightly deeper, had relatively steep sides and Magic Lake had gently sloping shores. The lakes were within 500 m of each other. Shortly after the lakes were made, blue-green algae blooms, weed growth and other signs of eutrophication occurred in Magic Lake, whereas Buck Lake remained clear *(Northcote, 1980)*.

If lake levels are to be altered to increase littoral area for fisheries purposes, such benefits must be balanced against the increased risks of winterkill. The concern about such effects are well founded. For example, a 4 m dam on the outlet of Corbett Lake, near Merritt, B.C., increased the littoral area from about 28% to 45% of the total surface area *(from map in Teraguchi and Northcote, 1966)*. Fish kills subsequently occurred in 6 out of 10 years *(Halsey, 1968)* and Corbett Lake must now be aerated to prevent winterkill.

Fisheries habitat improvement activities which involve changing lake levels must therefore take into account the potentially positive effects of production increase, the potential negative effects of winterkill and cost considerations for potential aeration programs.

5.1.3 Conditions in Reservoirs with Water Level Fluctuation

The effects of increased water levels and amplitude of fluctuation may be different depending upon the trophic level considered, the geographic location, the draw-down regime and, where fish are concerned, the species.

There are a number of responses among salmonids that characterize reservoirs with fluctuating water levels *(Elder, 1965)*. For a period of 2 or 3 years after flooding of large reservoirs there were improved growth rates and production of brown trout and char *(Elder, 1965; Runnstrom 1951, 1955)*. The patterns of response to reservoir formation and operation are not completely consistent. *Garnas and Hesthagen (1982)* found only weak negative effects on catch per unit effort, age composition and growth (brown trout) with increasing amplitude of reservoir fluctuation. *Rawson (1958)* reported short-term improvement in fishing in one reservoir in the Rocky Mountain region and found that productivity fell immediately in others. Similarly, *Jenkins (1967)* found that fish production peaked in the immediate post construction period and then declined to values which were lower than in the original stream enpondment. Spada Lake in Washington was impounded in 1965 and enlarged in 1984. The area of littoral zone and the production of benthos and plankton increased after an approximate 7 m lake level increase *(Stables et al., 1990)*. Angling use of the reservoir increased almost 6-fold after a further increase in lake level (1984) and then fell to one third of the high level it reached just after 1984 *(Stables et al., 1990)*. Spawning habitat was lost as a consequence of the increase in lake level.

There may be a number of reasons why temporary production increases occur following the elevation of water levels by reservoir formation *(Elder, 1965)*. Reservoir construction increases the forage area. Salts are leached from the flooded soil and terrestrial invertebrates either fall into or are flooded into the water. Decaying vegetation also provides food directly and contributes nutrients for food production by planktonic and semi-planktonic crustaceans.

Fish that can readily make use of available food may be successful in newly created reservoirs *(Cherry and Guthrie, 1975)*. In a four-year-old reservoir, in South Carolina, carp, suckers and catfish made effective use of detritus and the insects and crustaceans within it. Brown trout were scarce in the reservoir so their responses were not clear *(Cherry and Guthrie, 1975)*. Water level fluctuations had impacts on largemouth bass nesting success *(Mitchell, 1982)*. Increasing water levels reduced nesting success by causing lower water temperatures. Decreasing water levels stranded the nests *(Mitchell, 1982)*.

The long term impacts of increases in water level and water level fluctuation are detrimental to the production of bottom fauna *(Grimas 1961, 1962, 1964, 1965; Nilsson, 1961)*. In Lake Blasjon, Sweden, there was a 70% reduction in the bottom fauna in the zone of fluctuation following impoundment. Maximum abundance of the remaining fauna occurred just below the draw-down limit *(Grimas, 1961)*. Fluctuation of water level in Lake Blasjon also caused a change in composition of bottom fauna. It decreased the Gammarad species, large insect larvae and gastropods, but increased oligochaetes, nematodes and pisidians *(Grimas, 1962)*. There was a negative effect on fish food organisms in Lake Kultsjon, Sweden following lake level regulation. The heavy reduction of fish food organisms occurred directly as a result of draining and freezing *(Grimas, 1965)*. Char were affected less than brown trout by lake regulation *(Nilsson, 1961)*. Char fed upon plankton, which was less vulnerable to regulation than was bottom fauna. The abundance of large insect larvae remained high in a Norwegian reservoir where the rhythm of fluctuation was slow and the draw-down was restricted *(Grimas, 1964)*.

The construction of impoundments may cause increased shore erosion and water turbidity, altered temperatures and increased mercury contamination. Severe erosion and sediment deposition occurred in the littoral zone in Lake Blasjon, Sweden *(Grimas, 1962)*. There was very severe shoreline erosion *(Newbury and McCullough, 1984)* and sediment deposition *(Hecky and McCullough, 1984)* in Southern Indian Lake, Manitoba following a 3 m increase in lake level. [Responses in Southern Indian Lake may not be representative of those in B.C. because much of its original shoreline was in permafrost.]

Mercury levels increased in fish in three lakes in the Churchill River diversion project *(Bodaly et al., 1984)*. Mercury levels in pike and walleye from Southern Indian Lake increased from 0.2-0.3 µg/g to 0.5-1.0 µg/g. They were higher yet, 1.5-2.9 µg/g, in Rat and Notigi lakes. The area of these lakes had increased by 282% with flooding. Declines in mercury levels in most species of fish had not taken place within 5-8 years of flooding. Increase in mercury level in new impoundments and flooded lakes is not unusual and *Bodaly et al. (1984)* listed 4 or 5 cases where it occurred in locations other than Southern Indian Lake.

Although changes in lake conditions may be expected following the alteration of lake level, it is not easy to predict correctly the effects of such water level changes in a large system. In a review by *Hecky et al. (1984)*, eight impacts were correctly predicted, two were incorrectly predicted and 7 of 17 were not predicted at all.

5.1.4 Conditions in Reservoirs with Stable Water Levels

Many small impoundments, whether built by beavers or people, can benefit recreational fisheries by:

i) increasing the productive volume of the lake;
ii) increasing the littoral area and shoreline; and
iii) altering a lake's depth/volume relationship in a manner which reduces the likelihood of winterkill.

Reservoirs with stable water levels have two important fish production advantages over those that fluctuate. First, permanent littoral and riparian zone plant communities are established. Second, conditions of stable water levels plus such plant communities permit continuing production of benthic organisms.

5.1.5 Effectiveness of Littoral Areas as Over-winter Refuge Habitat

There are important differences in winter and summer behaviour of young trout. Metabolic requirements, food intake and swimming speeds are reduced during cold periods in the winter. The relationship between foraging behaviour and resting or hiding also changes. The vulnerability to predation by homiotherms is higher and the role of refuge habitat is therefore more critical. It is well known that young salmonids, in streams, seek cover by day and move out from cover at night during winter. There is less information on ecological behaviour of young trout in lakes during winter than there is for streams. However, many of the temperature-induced physiological conditions might be expected to be the same. The use of refuge habitat in lakes is expected to be important during winter. One paper indicates the use of such habitat. Flooded shoreline vegetation provided cover for juvenile rainbow trout stocked in mid-elevation reservoirs in Utah *(Tabor and Wurtsbaugh, 1991)*. During the day young trout were in the littoral zone of two reservoirs that were studied. They selected the most structurally complex habitats i.e. large boulders, inundated vegetation and small rocks and avoided open areas of sand and gravel bottom. However, during night they did not show as strong a preference for structurally complex habitats *(Tabor and Wurtsbaugh, 1991)*.

5.2 REVIEW OF CONSTRUCTED PROJECTS

5.2.1 Project Success

A total of 28 lake manipulation projects were identified in B.C. and Alberta. These included17 projects where lake levels were increased, 5 where lake level and through-low were increased and 6 sites (all in Alberta) where new lakes were created in the end pits of coal mines.

A synopsis of the collected information is compiled in APPENDIX 6 and a summary is compiled on *Table 3*. As indicated below, 78% of all rated projects were either a moderate or outstanding success:

SUCCESS RATE	NO. OF PROJECTS	% *1	
Unknown	5	na	
Failure	2	9	22
Limited Success	3	13	
Moderate Success	7	30	78
Outstanding Success	11	48	
TOTAL # OF PROJECTS	28		

*1 of the rated projects

It is, however, important to realize that the criteria used in this evaluation varied with the perspective of the individual or individuals from whom we obtained our information. For example, some raised lakes in B.C. and most of the constructed lakes in Alberta created a successful fishery. However, these lakes are generally not self-sufficient as they require annual stocking and, in the case of B.C., aeration to prevent winterkill is required at some sites. Despite these functional limitations, a number of the projects in B.C. and Alberta were rated as being an outstanding success. In contrast, other contacts

used stocking, aeration or other maintenance requirements as a basis for rating projects as being only a limited or moderate success. Despite this shortcoming, the survey clearly indicates that it is possible to create or enhance lake fisheries. What is not well known is how well fish production will be sustained over the long term as the recently created lakes continue to mature and the initial input of nutrients is expended.

It is instructive that five of 28 or 18% of the identified projects did not have enough data to reliably assess their performance.

Due to the small sample size, it is difficult to compare the success rates between projects which manipulated lake level only, increased lake level and augmented flow or created new lakes. The available information is, however, shown below:

SUCCESS RATE	LAKE LEVEL			LAKE LEVEL AND FLOW			NEW LAKE		
	NO. OF PROJECTS	% *1		NO. OF PROJECTS	% *1		NO. OF PROJECTS	% *1	
Unknown	5	na		0	na			na	
Failure	2	17	34	0				0	17
Limited Success	2	17		0			1	17	
Moderate Success	3	25	67	1	20	100	3	50	83
Outstanding Success	5	42		4	80		2	33	
TOTAL # OF PROJECTS	17			5			6		

*1 of the rated projects

This comparison suggests that augmenting flow as well as increasing lake level may be desirable.

5.2.2 Factors Affecting Project Success

The information presented in APPENDIX 6 indicates that the following factors were identified as having caused difficulties with the constructed projects:

- inadequate water supply or seasonal draw-down which dried up littoral areas;
- truck and shovel construction techniques which leads to deep lakes with <15% littoral areas;
- deep lakes in which the hypolimnion becomes anoxic;
- physical instability in the littoral area or shoreline erosion;
- insufficient littoral area which reduced primary productivity;
- excessive littoral area which resulted in warm water temperatures and an increased frequency of winterkill;
- elevated Cu or Mo concentration in lake sediments or in the water column; bio-accumulation of Cu, Mo, Se or Hg;
- inadequate design, construction or maintenance which led to physical failure of weirs, channels, etc.;
- lack of suitable inlet or outlet spawning habitat;
- physical barriers between lake outlet spawning area and lake rearing habitat;
- provision of lake inlet or outlet spawning habitat which does not match the genetic predisposition of the fish involved;

- loss of fish through the outlet channel;
- beaver dams which inundate spawning habitat;
- competition from non-sport fish or excessive fishing pressure;
- lack of riparian cover leading to high rates of predation;
- lack of a self-sustaining fishery which necessitates an annual stocking program;
- cost of annual stocking, provision of aeration programs or other maintenance activities;
- reduced aesthetic appeal due to a lack of landscaping or riparian reclamation work; and
- lack of a comprehensive monitoring or reporting policy.

In contrast, factors which we identified as have contributed to successful projects included:

- a stable water supply and/or lake levels;
- the presence of groundwater inflow;
- an integrated design which included raising lake levels, augmenting the water supply and the construction of fisheries habitat;
- raised lake levels which increased the available littoral areas and decreased the potential for winterkill;
- drag line construction techniques which resulted in shallow (<20 m) water depths and the presence of 25 to 40% littoral areas;
- the presence of both an inflow and outflow channel which increased the through-flow of water and decreased the potential for winterkill;
- strong winds, lake orientation and shallow water depths which permitted mixing and reduced the risk of winterkill;
- supplemented aeration programs to prevent winterkill;
- high $CaCO_3$ concentrations which reduced the toxicity of elevated Cu concentrations;
- elevated TDS values leading to high potential productivity (although productivity was not actually measured);
- initial post-construction availability of nutrients;
- riparian vegetation and reclamation activities which provided a source of nutrients;
- strong invertebrate production and high dissolved oxygen concentrations;
- adequate water quality;
- annual fry stocking in lakes with mono-cultures;
- stocking 1-year old trout in lakes with competition from non-sport fish;
- lack of vehicle access which resulted in lower fishing pressure;
- restrictive fishing regulations;
- drag line construction techniques which resulted in a natural appearing lake and riparian area; riparian replanting and other reclamation work which provided an aesthetic showing; and
- community involvement in the design construction and operation of the project.

5.2.3 Summary

Raising lake levels may result in both positive and negative effects.

Newly flooded areas will release nutrients and enhance production at the bottom of the food chain. This effect will last for a few years and then decline. There will be an increase in the terrestrial food organisms that fall into the water or are caught up in the level increase. This effect will also be of short duration. If the flooded shoreline was vegetated, there would be an increase in the complexity and amount of cover. This should have a positive effect on trout production. However, there is also a negative side to this as flooded areas are unsightly and may in fact be dangerous to boaters if they contain snags.

The effects of increasing lake levels on perimeter length, percent of shoal or littoral area and lake volume to depth ratio will depend on the morphometry of the lake basin and the character of the terrain around it. If the shore area that is flooded is flat and extensive compared to the existing littoral zone, there will be a large increase in productive littoral area. However, the creation of an extensive littoral areas will also increase the risk of winterkill. If the lake is deep with steep sides, and if the surrounding land is steep, an increase in lake level will alter volume to area relationships but will not have a major impact on perimeter dimensions or the percentage of littoral area.

The effect of raising lake levels is therefore dependent on individual site characteristics. There is no single set of responses that may be expected for all lakes and there may be both positive and negative effects associated with any water levels manipulation scheme.

6.0 CONSTRUCTION OR ENHANCEMENT OF SPAWNING/REARING CHANNELS

A small number of artificial channels have been constructed at lake inlets and outlets to provide spawning or spawning and rearing habitat. In some cases the channels are only operated seasonally as their objective is to simply provide a place for fish to spawn so that they do not become egg or milt-bound *(e.g. Plates 1 and 2)*. In this circumstance the channel may be seasonally deactivated as there is no requirement to produce fry. This occurs most frequently in stocked lakes. In other situations, fry production is desired and the channels have been primarily designed to provide spawning habitat. Rearing habitat for fry is produced incidentally. More commonly, existing stream channels have been enhanced to provide improved spawning or rearing capability. The performance of each of these types of channels is reviewed in this section.

6.1 TECHNIQUES FOR QUANTIFYING STREAM SPAWNING AND REARING HABITAT

The B.C. Government Resource Inventory Committee (RIC), the B.C. Forest Practices Code and Forest Renewal B.C.'s Watershed Restoration Program (WRP) have recently produced a number of guidelines for assessing stream channel morphology and fisheries habitat. Relevant publications include:

A: Resource Inventory Committee

- Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures *(Ministry of Fisheries, 1998a)*;
- Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Data Forms and Users Notes, *(Ministry of Fisheries, 1998b)*;
- Standards for Fish and Fish Habitat Maps *(Ministry of Fisheries, 1998c)*; and
- Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Lake Survey Form Field Guide *(Ministry of Fisheries, 1999a)*;

B: Forest Practices Code

- Channel Assessment Procedure Guidebook *(Anonymous, 1996)*;
- Coastal Watershed Assessment Procedure Guidebook *(Anonymous, 1995a)* and Interior Watershed Assessment Procedure Guidebooks *(Anonymous, 1995b and 1998a)*; and
- Fish–Stream Identification Guidebook, Second Edition *(Anonymous, 1998b)*.

C: Watershed Restoration Program

- Fish Habitat Assessment Procedures *(Johnston and Slaney, 1996)*;
- Channel Conditions and Prescriptions Assessment Interim Methods (Hogan, Bird and Wilford, 1996); and
- Fish Habitat Rehabilitation Procedures *(Slaney and Zaldokas, 1997)*.

It is beyond the scope of the present project to review all of these procedures. We have, however, been requested to provide comments on the ability of these guidelines to quantify spawning and rearing habitat. Measures to assess the productive capacity of spawning or rearing habitats is also of interest if these procedures are to be used to either document the extent of lost habitat or determine the value of replacement habitat.

The RIC guidelines provide standardized procedures for conducting overview (1:20,000 scale) assessments of stream channel characteristics and fish habitat. The procedures are not intended, nor are they suitable, for quantifying the areal extent or productive capacity of spawning or rearing habitat. For

example, procedures for assessing rearing habitat cover do not provide a system for quantifying the area or, more importantly, the volume and complexity of cover that would be functional within specified flow ranges.

Similarly, the recommended procedures do not address the mosaic of features which are required to assess spawning habitat. As illustrated in *Hartman and Galbraith (1970)*, adequate spawning habitat must include more than just appropriately sized gravel. Factors such as the availability of cover, water depth and velocity during the incubation period must all be suitable.

The Forest Practices Code channel and watershed assessment procedures *(Anonymous, 1995a, b; 1996 and 1998a)* and the three Watershed Restoration Program documents provide some guidance of watershed or channel "health" but do not specifically address the quality or productive capacity of spawning and rearing habitat.

Spawning or rearing habitat can be identified on the basis of previous local experience with similar stocks or, if a more formal assessment is required, by developing probability of use curves similar to those published in *Bovee and Cochnauer (1977)* or *Bovee (1978)*. However, it is important that potential temporal changes in the distribution of these habitats is recognized. This is particularly relevant in situations where channel regime or morphometry is changing due to land use or climatic variation. For example, *Figure 4 (from M. Miles and Associates Ltd., 1999a)* illustrates the changes in channel morphology which have occurred over a 50-year period on a coastal stream located near Powell River, B.C. Riparian and upslope logging activities can be seen to have significantly affected the stability of the river banks and the sediment supply. The photo sequence illustrates the resulting changes in channel morphology and associated rainbow trout habitat. These impacts are still evident 40 years after logging. *Figure 5 (from M. Miles and Associates Ltd. 1999b)* illustrates the dramatic changes in channel regime which have occurred following valley bottom logging and flow diversion on a stream located near Campbell River on Vancouver Island. The channel shows only modest recovery after a period of 38 years. Although only two examples are illustrated here, experience indicates that this pattern of impact and slow recovery is repeated commonly.

The two examples discussed above demonstrate the benefit of assembling the historical air photos to determine how channel morphology and the distribution of fish habitat has varied over the period of record. Mapping units such as "river reaches" can be seen to be dynamic and can be expected to evolve over time as a result of changes in sediment loadings, river bank stability, riparian land use or climatic variation. This implies that stream habitat inventories or assessments will need to be periodically updated in evolving alluvial channels.

Seasonal variability must also be considered when assessing both the extent and capability of potential habitat features. This is particularly important in the north where the winter low flow conditions, ice effects, etc. can significantly affect habitat availability or suitability.

The implication of the above observations is that channel or fish habitat assessment is a complicated process which requires considerable physical and biological experience and an understanding of how physical processes affect fisheries habitat formation *(e.g., see Kellerhals and Miles, 1996)*. FRBC and WRP guidebooks provide a standardized methodology for data collection which can be employed by people with relatively little training. However, the guidelines provide only comparatively simple advice on how to interpret the collected data, and the indices of channel impact are only first approximations at best. An experienced geomorphologist or biologist may be able to make some interpretations from the information compiled using these guidelines. First hand interpretations are, however, likely to be much more reliable. This implies that inventories for No Net Loss assessments or other substantive purposes should be undertaken by senior scientists (preferably a team consisting of a geomorphologist and a biologist) using inventory procedures developed on a project specific basis.

There are many models that have been developed to assess the productive capability of stream systems (e.g. *Fausch et al., 1988; Korman et al., 1994; Ptolemy, 1995).*

The 99 models reviewed by *Fausch et al. (1988)* were organized and evaluated by habitat variables used, mathematical structure, size of data set and effectiveness of fitting the model to the data set. The models used to predict "standing crop of stream fish" were of five types based on drainage basin characteristics, channel morphology, flow, habitat structure (biological, physical and chemical) and weighted useable area.

Korman et al. (1994) evaluated the predictive capabilities of 91 stream and 87 lake models. Different models were useful for four different types of analyses:

- stock management decision making;
- evaluation of stream and lake restoration methods;
- help in evaluation of habitat impacts; and
- examination of the relative benefits of mitigation techniques.

Korman et al. (1994) ranked models for these four types of analysis, according to their efficacy for use in B.C. Many of the models reviewed in *Korman et al. (1994)* were the same as those evaluated in *Fausch et al. (1988).* Different models use different variables, frequently in linear or multiple regression analyses, to predict fish production capability. Historically, some models have been misused *(Korman et al., 1994).* Many models are specific for a geographical area and are poor predictors in new areas.

Density of fish, alkalinity and conductivity were positively related in analyses of data from 240 B.C. streams *(Ptolemy, 1995).* Ptolemy's model was highly rated by *Korman et al. (1994),* however, a limitation was that it only predicted abundance of fish in prime habitats.

Regardless of the types of model used, it is critical that habitat measurements or estimates are accurate and can be extrapolated from reaches where they are made to other reaches. *Dolloff et al. (1993)* reported discrepancies between the Representative Reach Extrapolation Techniques (RRET) and the Basinwide Visual Estimation Techniques (BVET). The sampling method in the BVET avoided estimation errors.

There is concern that fisheries and habitat mangers may rely too heavily on cookbook formulae and models in decision making. The behaviour of natural systems is characterized by complexity and uncertainty (see process diagrams in *Hartman and Scrivener, 1990*). We may never escape the need to use models, however, such use must be accompanied by an understanding of the complexity of natural systems and a recognition of the processes that are being "managed". Development of an understanding of the natural systems about which we make decisions can be impeded by political expediency, budget constraints and an aversion to "more research". Better decisions will be made so long as the use of models is tempered with caution and understanding. If they are used "blindly" as quick-fixes, poorer decisions will result.

6.2 REVIEW OF PREVIOUS PROJECTS

A review of projects to create spawning channels and improve existing inlet or outlet spawning or rearing facilities is presented in APPENDIX 7. The results update some of the analyses previously presented in *Hartman and Miles (1995)* and include new projects.

Project performance is summarized in *Table 4* on the basis of subjective assessments made by regional staff. The fourfold classification system is the same as that used in *Hartman and Miles (1995)*. The review indicates the following success ratios:

SUCCESS RATE	NO. OF PROJECTS	% *1	
Unknown	4	na	
Failure	16	34	57
Limited Success	11	23	
Moderate Success	8	17	43
Outstanding Success	12	26	
TOTAL # OF PROJECTS	51		
TOTAL # OF RATED PROJECTS	47		

*1 of the rated projects

Fifty-seven per cent of the projects had limited or no success and 43% were considered moderately or outstandingly successful.

Four of the twelve projects listed as outstanding successes simply involved pumping water into an excavated channel to allow fish to spawn so that they would not become egg-bound. After the eggs were laid the pumps were turned off and the eggs died. If these projects (which are comparatively simple to design, construct and operate) are omitted the success statistics are as follows:

SUCCESS RATE	NO. OF PROJECTS	% *1	
Unknown or omitted	8	na	
Failure	16	37	63
Limited Success	11	26	
Moderate Success	8	19	37
Outstanding Success	8	19	
TOTAL # OF RATED PROJECTS	43		

*1 of the rated projects

This revised analysis indicates that 63% of the constructed projects had limited or no success and 37% had moderate or outstanding success. Given the generally short period over which these projects have been operating, it is likely that the long term success will be lower than 37% unless regular monitoring and maintenance are carried out.

It is instructive that four projects or nearly 10% of the total have no follow-up information. In addition, success criteria for the other projects was, in the majority of cases, only available from local managers (rather than from actual reports). These results are similar to those reported in *Hartman and Miles (1995)* and indicate the scarcity of post-construction monitoring and reporting. This observation is particularly relevant to government sponsored projects which do not have legal or contractual requirements for monitoring and documentation of performance.

We have subjectively ranked each of the projects in *Table 4* to indicate the design complexity of the construction or maintenance process.

PROJECT COMPLEXITY, CONSTRUCTION AND DESIGN EFFORT	CODE	NUMBER OF PROJECTS	% OF PROJECTS
Gravel placement in existing channel, little channel preparation	1	20	41
Gravel platform construction, rock or wood weirs to hold gravel in place	2	10	20
Gravel platform construction, plus cover	3	3	6
Spawning channel in existing stream, channel preparation before gravel placement	4	3	6
Constructed spawning channel - pumped water supply	5	7	14
Constructed spawning channel - natural water supply	6	2	4
Designed channel for spawning with rearing habitat components - cover	7	4	8
TOTAL NUMBER OF PROJECTS (2 projects uncoded)		49	

This analysis indicates that 81% of the projects have merely involved the placement of spawning gravel or the construction of gravel platforms. Seven of the thirteen newly constructed channels (54%) have a pumped water supply and four (31%) have no fry recruitment as the pumps are turned off once the fish have spawned. This analysis implies that most experience with rainbow trout enhancement has been with projects which are comparatively simple to design or operate.

Project success as a function of the project complexity is summarized below:

SUCCESS	SUCCESS AS A FUNCTION OF DESIGN COMPLEXITY [*1]													
	1		2		3		4		5		6		7	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Failure	6	33	3	33	1	33	2	66	2	25	1	50	2	50
Limited Success	6	33	2	22									1	25
Moderate Success	4	22	3	33			1	33			1	50		
Outstanding Success	2	11	1	11	2	66			6	75			1	25
TOTAL # OF RATED PROJECTS	18		9		3		3		8		2		4	

This analysis is compromised by the small number of projects. It does, however, indicate that simple projects, such as placing gravel or constructing gravel platforms, have 66% and 55% failure rates, respectively. Experience again indicates that these types of projects deteriorate with age and, without maintenance, the long term success is likely to be even lower. This analysis therefore implies that it is difficult to create successful spawning or rearing habitat, particularly if regular maintenance and repair cannot be assured.

6.3 FACTORS AFFECTING PROJECT SUCCESS

A review of the information presented in APPENDIX 7 indicates that the following factors caused difficulties with the constructed projects:

- lack of water supply, intermittent water supply or pump failure;
- water quality impacts due to cattle or high pH;
- loss of spawning gravel due to high flows or the action of spawning fish;
- sediment deposition in spawning gravel due to local bank erosion or upstream sediment production;
- nest superimposition;
- fish poached or taken by bears due to low standing water;
- inadequate assessment of limiting factors, (e.g. spawning habitat constructed but rearing habitat not available);
- predation by non sport fish (e.g. burbot and squawfish);
- impacts due to land use changes (e.g. logging road, bridge construction, mining, etc.);
- channel instability due to large flood flows or steep channel gradient (3.5 to 5%);
- inadequate channel gradient resulting in sediment deposition; and
- access difficulties due to channel constrictions or barriers and beavers.

In contrast, factors which contributed to successful projects included:

- adequate stream flow in low-gradient streams;
- well engineered channel constructed with filter cloth, rip-rap and gravel;
- annual gravel cleaning or placement; and
- upstream sediment control measures.

Careful site selection is probably the single most important factor affecting the physical success of spawning and rearing channels. Our experience indicates that it is desirable to locate channels on stable fans, along the base of the valley wall or in other areas where local drainage can be expected to augment the surface water supply. However, even with pre-project site assessments, it will be difficult to predict the volume and quantity of water which will be available. The amount of available water will dictate the area or length of channel which can be built. In addition, increasing atmospheric CO_2 concentration is predicted to result in warmer and dryer summers in much of B.C. *(e.g. Figure 6)*. Thus, there is unavoidable uncertainty about both the present and future water supply. It is important that designers size proposed channels on the basis of conservative estimates of the potential water supply and the magnitude of peak flood events. Maintenance requirements can also likely be reduced if the channel width and depth, rip-rap size, measures needed to hold spawning gravel in place, etc. are calculated on the basis of hydraulic geometry relationships and engineering design guidelines *(e.g. Roads and Transportation Association of Canada, 1973 and 1980; Newbury and Gaboury, 1993; Hey and Heritage, 1993; Shrubsole, 1994; U.S. Government, 1998)*.

From a biological perspective, the size and age of young trout produced from improved spawning areas or channels must be suitable for the environment into which the fish go. If the lake, into which the young fish migrate, supports large numbers of non-sport fish, the recruited trout should be large (one year old or more). Smaller fish are more vulnerable to predation. In cases where it is important that young fish are large before they enter a lake, outlet spawning may be an advantage. In Loon Lake, B.C., most of the young fish entering the lake from the outlet were 1 + in size. Those entering the lake from the inlet were fry. The Loon Lake situation may not pertain in all cases, however, it serves as a guide for what type of recruitment to expect from outlet and inlet spawning populations.

7.0 PHYSICAL AND ECOLOGICAL EFFECTIVENESS OF DIVERSION CHANNELS AROUND PITS, ROCK DUMPS AND TAILINGS OR SETTLING PONDS

Mining developments can require the construction of open pits, waste rock piles, settling or tailing ponds and a network of roads. In some circumstances, it is possible to construct a diversion channel around these structures to either pick up seepage water or re-establish a pre-existing water course. We have attempted to identify as many of these types of projects as possible and determine their performance. However, despite extensive interviews and a review of annual reclamation reports filed with the B.C. Ministry of Energy, Mines and Petroleum Resources, we have only been able to locate 7 mine sites with relevant projects. Three are in B.C., 1 is in Yukon, 2 are in Alberta and 1 is in the NWT.

7.1 REVIEW OF PREVIOUS PROJECTS

The identified diversion projects are described in APPENDIX 8 and this information is summarized on *Table 5*. A total of 10 diversions were identified at the 7 mine sites. No data are available on 2 of these projects. Success statistics are as follows:

SUCCESS RATE	NO. OF PROJECTS	% *1	
Unknown	2	na	
Failure	3	38	63
Limited Success	2	25	
Moderate Success	2	25	38
Outstanding Success	1	13	
TOTAL # OF PROJECTS	10		

*1 of the rated projects

Sixty-three per cent of the projects are classified as being a failure or of limited success and 38 per cent are a moderate or outstanding success. These statistics obviously suffer from the small sample size. Nevertheless the results indicate that over half of the constructed diversion channels do not successfully provide fish habitat.

7.2 FACTORS AFFECTING PROJECT SUCCESS

A review of the information in APPENDIX 8 indicates that it is difficult to create stable diversion channels if a pit or rock dump is located in a steep gradient area. In contrast, settling or tailings ponds are commonly located in the valley bottom. The imposed channel gradients are generally less severe and this will increase the likelihood of creating a stable channel which can support fish.

The most successful identified project is a diversion at the Coal Valley Mine in Alberta. This 2.3 km long diversion channel was extensively enhanced for fish. Complexity was provided through woody debris and boulder placement, holding pools were created, spawning habitat constructed and the entire channel was lined with pit run gravel. Discussions with *Dane McCoy (pers. comm.)* indicate that the channel cuts across a wetland complex which may help to regulate peak flows. This also suggests this channel is a low gradient and low energy system.

The Ekati project in the NWT is also instructive as only a small amount of fisheries habitat was initially constructed in this diversion channel. Intensive biological and hydraulic monitoring will be undertaken over the next 10 years and additional habitat development will be undertaken on an "adaptive basis" once successful strategies have been identified.

7.3 RECOMMENDATIONS FOR DESIGN OF ECOLOGICALLY FUNCTIONING DIVERSION CHANNELS.

7.3.1 Hydrology and Hydraulics

As discussed in SECTION 6, it is important that all channels be designed on the basis of the expected flows *(e.g. Hardy BBT Ltd., 1990)*. Channel linings, bank revetments, drop structures or other engineering works may be required to produce a more or less stable channel. Documents by *RTAC, 1973; Newbury and Gaboury, 1993, Hey and Heritage, 1993; Shrubsole, 1994, U.S. Government, 1998* and *U.S. Army Corps of Engineers et al., 1999*, provide information on appropriate engineering and environmental techniques.

The kinds of habitat enhancement structures which are appropriate for a specific setting must be determined on the basis of both biological requirements and the physical conditions within the channel. Previous reviews indicate that instream enhancement projects typically have 20 to 50% success rates over periods of less than a decade *(see M. Miles, 1997)*. In large measure, this reflects the selection of structures which were inappropriate for the discharge or sediment load which had to be accommodated. Most fisheries enhancement guidelines *(e.g. Adams and Whyte, 1990; Slaney and Zaldokas, 1997)* do not provide quantitative criteria for selecting or sizing instream structures. The *U.S. Government (1998)* makes some steps towards this process and a paper by *Brookes (1990)* provides stream power criteria (calculated from slope and bankfull discharge) to assess the stability of structures placed in sand bed channels. Unfortunately, more quantitative measurements would be required to generate similar criteria for streams in B.C. A factor that is not commonly considered is that natural stream channels are in equilibrium with the channel gradient, the discharge and sediment load they must carry and the characteristics of the river bed and the channel banks. Changing any of these factors will alter the stream morphology and if the individual or cumulative alterations exceed poorly-defined threshold conditions, then resulting changes in channel characteristics can be very large *(see Schumm, 1977; Kellerhals, 1982; Kellerhals and Church, 1989; Church, Ferguson and Kellerhals, in draft; and Ashmore and Church, in press)*.

7.3.2 Biological Considerations

We found little information about biological conditions and fish production in diversion channels around major mine features. However, full biological function to replicate natural, sustaining fish production habitats for spawning and/or rearing requires several elements:

i) Water quality conditions such as pH, oxygen, ammonia and turbidity must be appropriate. The production of algae within streams requires a balance of nutrient elements in adequate concentrations. The concentrations of heavy metals must be within the regulatory standards. It will be difficult to reliably predict these concentrations within the different types of channels which occur around a mine;

ii) Water temperature regimes must be appropriate for trout. If a channel is exposed to radiant energy for a considerable distance, the water will heat up. A functional channel therefore requires canopy cover for temperature regulation. The amount of canopy cover needed will

depend upon stream width, duration and intensity of insolation, air and ground temperature, travel distance and the temperature of originating water. The amount of ground water input will also affect the thermal regime. The numerical values assigned to these elements will depend upon the local situation;

iii) The hydrological regime must provide adequate spawning and rearing flows. It must also provide periodic flushing events adequate to re-condition spawning gravel and maintain habitat. However, these should not be so high that they permanently destroy fish and habitat structure. Natural streams have ground water input to their channels. The location and amount of such ground water determines the location of spawning areas for Dolly Varden and bull trout *(Baxter and McPahil, 1999)*. The presence of cover near spawning sites is also important;

iv) The channel structure must provide cover appropriate for different life stages and seasons depending upon the life histories of the fish present. The channel must contain a mosaic of gravel patches and holding cover for spawning trout if it is used for reproduction;

v) A naturally functioning channel must be bordered by a complex of riparian vegetation species. The species composition of such vegetation will depend upon the geographic situation. Aside from providing shade, riparian vegetation provides cover and allochthomous material for trophic processes within the stream; and

vi) Natural channels contain an array of benthic invertebrates. Some of the species of *Ephemeroptera* and *Plecoptera* (mayflies and stoneflies) are indicative of water quality. Local species that fill such a role should be looked for in re-constructed channels. A wide array of benthic invertebrates will quickly colonize a channel if water quality is satisfactory.

These requirements and considerations are listed in very general terms. There has been no intention to quantify the identified elements. The essential point in this listing is that if diversion channels are to be built and operate as parts of a functional and productive lake-stream system, all of the elements listed must be considered during design, construction and operation.

8.0 CONCLUSIONS

The analyses undertaken in this study indicate that the success rate [*1] for the investigated fisheries enhancement or compensation strategies is as follows:

PROJECT TYPE	SUCCESS RATE %
Aeration	80
Lake level or flow increase (all types)	78
lake level only	67
lake level and flow	100
new lake	83
Spawning/rearing channels (all types)	43
Spawning/rearing channels - fry not killed	37
Ecologically effective diversion channels	38

These results suffer from a number of limitations:

i) the sample sizes are small;
ii) success criteria are subjective and may not have been uniformly applied; and
iii) many projects have only been recently constructed and the long term success is unknown.

Nevertheless, these data suggest that aeration projects and manipulations of water levels to enhance fisheries production can be successfully undertaken in some types of lakes. Preceding sections of this text have attempted to define the factors which predispose a site to success or failure. Despite this guidance, there will still be unavoidable uncertainty in this assessment and it may therefore be difficult to reliably predict how well proposed aeration or lake level manipulation projects will work. A second concern is that aeration and lake level manipulation projects require continued operational and maintenance funding and, in the case of aeration, these costs can be considerable if the site does not have a nearby reliable power source. Our analyses also suggest that lake aeration projects were comparatively less successful if they relied on a diesel generator for power or if they were located in isolated areas where it was difficult to readily check on the machinery.

Many of the identified lake manipulation projects (as in the Alberta end pit lakes) were operated as a "put and take" fishery as they could not produce a self-sustaining fisheries population, nor could they sustain the fisheries pressures placed upon them. Projects such as Trojan Pond in the Highland Valley, B.C. were "outstandingly successful" in that they produced large trout. However, the fish are inedible due to elevated copper concentrations, the former settling pond is devoid of riparian vegetation and the adjacent surface has recently been treated with bio-solids. Thus, while the replacement lake is deemed to be an "outstanding success", it does not presently provide the same fishing experience which would occur at a natural lake. In addition, there has not been the opportunity to monitor the long term evolution of water quality, fisheries productivity or other conditions in manipulated lake environments. Therefore, until this information is available, the eventual success rate of Trojan Pond or other artificial lakes is unknown.

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1 i.e. projects which we rated as being a moderate or outstanding success.

Our analyses indicate that less than half of the spawning or spawning/rearing channel projects were successful. In addition, many successful sites required either pumps to provide a water supply or regular maintenance to ensure gravel quality. For this reason, many of the constructed channels are not self-sustaining and on-going maintenance funding is required.

Our analyses suggest that slightly more than one-third of the identified diversion channels were capable of sustaining a fishery. Channels commonly eroded and fisheries structures were destroyed by flood flows. These results are similar to those presented in *Hartman and Miles (1995), Miles (1997) and Pattenden et al. (1998).*

The frequently documented failures of instream structures are thought to result from:

i) inadequate knowledge or understanding of site conditions;
ii) a lack of quantitative guidelines for selecting and designing appropriate structures;
iii) inadequate design and/or construction;
iv) lack of maintenance; and
v) attempting to provide static "structures" rather than setting up conditions where river processes will create the required habitat.

From a biological perspective, it is difficult to both identify the "sequence of key factors that limit production" *(see Miles et al., 1999)* or assess a project's effect on fish productivity. Despite these limitations, it is our opinion that short sections of ecologically effective diversion channels can be constructed as long as the gradient or stream discharge (i.e. stream power) is not excessive. However, adequate physical and biological work must be undertaken to define habitat requirements. Also the project budget must be sufficient to provide for competent design, construction, monitoring, post-construction assessments and on-going maintenance, fine-tuning or periodic reconstruction. Even with this process, an initial loss of production is likely to occur.

In situations where stream flows or channel gradients are significantly increased, it may not be possible to construct diversion channels which have habitat values similar to that in the pre-existing channel. This is particularly important in situations where poorly defined threshold values between one type of channel regime and another are crossed.

The documented success rates for spawning/rearing channels and ecologically effective diversion channels are a concern as most projects have been recently constructed. Longer term success rates are therefore expected to be even lower than the documented 38% to 43% and additional research will be required to determine and quantify the factors which contributed to failure or success. It is therefore recommended that a representative sample of the sites identified in this report be inspected and a systematic program of measurements or analyses be undertaken to document the factors which have affected the hydrotechnical and biological performance. These data should then be used to prepare quantitative design criteria for future projects.

9.0 SOURCES OF INFORMATION

9.1 REFERENCES

Adams, Mark A. and Ian W. Whyte. 1990. *Fish Habitat Enhancement: A Manual for Freshwater, Estuarine and Marine Habitats.* Dept. of Fisheries and Oceans, Canada. DFO 4474. 330 p.

Anonymous. no date. *Peter Hope Lake: Restoring a Balance.* B.C. Fisheries Branch, Kamloops, B.C. and Ducks Unlimited, Kamloops, B.C. 5p.

_____ 1993. *The Yukon Placer Authorization and Supporting Documents: Applicable to Placer Mining in the Yukon Territory.* Government of Canada, Ottawa, Canada. 114 p.

_____ 1995a. *Coastal watershed assessment procedure guidebook (CWAP): Level 1 analysis.* Forest Practices Code of British Columbia. Published by B.C. Environment. 66p.

_____ 1995b. *Interior watershed assessment procedure guidebook (IWAP): Level 1 analysis.* Forest practices code of British Columbia. Published by B.C. Environment. 82 p.

_____ 1995c. CANADIAN WATER QUALITY GUIDELINES. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environment Ministers. Environment Canada, Ottawa.

_____ 1996. *Channel Assessment Procedure Guidebook.* Forest Practices Code of B.C. 37 p.

_____ 1997. *Report of the EUB-CEAA Joint Review Panel, Cheviot Coal Project, Mountain Park Area, Alberta.* Alberta Energy and Utilities Board and Canadian Environment Assessment Agency. 161 p. plus Appendices.

_____ 1998a. *Interior Watershed Assessment Procedure Guidebook (IWAP).* Forest Practices Code of B.C. 78 p.

_____ 1998b. *Fish-Stream Identification Guidebook: 2ND Edition.* Forest Practices Code of B.C.
Ashley, K.I. 1981. *Winterkill Limnology/aeration Program: Past, Present and Future.* Unpublished report for Fisheries Research Section. 21 p.

_____ 1983. *Hypolimnetic Aeration of a Naturally Eutrophic Lake: Physical and Chemical Effects.* Can. J. Fish. Aquat. Sci. 40(9): 1343-1359.

Ashley, K.I. 1985. *Hypolimnetic Aeration: Practical Design and Application.* Wat. Res. 19: 735-740.

Ashley, K.I. and K.J. Hall. 1990. *Factors Influencing Oxygen Transfer in Hypolimnetic Aeration Systems.* Verh. Internat. Verein. Limnol. 24: 179-183.

Ashley, K.I., K. Tsumura and B.M. Chan. 1992. *Fisheries Management of Winterkill Lakes in Southern Interior British Columbia.* In: R.D. Roberts and M.L. Bothwell (eds.) Aquatic Ecosystems in semi-arid regions: Implications for resource management. N.H.R.I. Symposium Series 7, Environment Canada, Saskatoon, Saskatchewan. pp. 287-297.

Ashmore, P. and M. Church. (In press). *Environmental Change and Rivers in Cordilleran Canada.* Geological Survey of Canada Bulletin.

Bandow, F. 1986. *Evaluation of Winter Aeration Techniques in Minnesota.* Section of Fisheries, Investigation Rept. No. 306, Div. of Fish and Wildlife, Minnesota Dept of Nat. Resources, 48 p.

Barica, J. 1975. *Summerkill Risk in Prairie Ponds and Possibilities of its Prediction.* J. Fish. Res. Board Can. 32(8): 1283-1288.

Barnett, I. 1992. *Habitat Conservation Fund: Kidd Lake Proposal, Ducks Unlimited Canada.* Unpublished proposal for the Habitat Conservation Fund by Ducks Unlimited, Kamloops, B.C. 11p.

Baxter, J.S. and J.D. McPhail. 1999. *The influence of redd site selecton, ground water upwelling and over-winter incubation temperature on survival of bull trout (salvelinus confluentus) from egg to alevin.* Can. J. Aool. 77:1233-1239.

Bernhardt, H. 1967. *Aeration of Wahnback Reservoir Without Changing the Temperature Profile.* Am. Water Works Ass. J. (Aug.): 943-964.

Bodaly, R.A., R.E. Hecky and R.J. Fudge. 1984. *Increases in Fish Mercury Levels in Lakes Flooded by the Churchill River Diversion, Northern Manitoba.* Can J. Fish. Aquat. Sci. 41(4): 682-691.

Bovee, Ken D. 1978. *Probability-of-Use Criteria for the Family Salmonidae.* Instream Flow Information Paper No. 4. Cooperative Instream Flow Service Group. Western Energy and Land Use Team, Fish and Wildlife Service, U.S. Department of the Interior.

Bovee Ken, D. and Tim Cochnauer. 1977. *Development and Evaluation of Weighted Criteria, Probability-of-Use Curves for Instream Flow Assessments: Fisheries.* Instream Flow Information Paper No. 3. Cooperative Instream Flow Service Group. Western Energy and Land Use Team, Fish and Wildlife Service, U.S. Department of the Interior.

Brauhn, J.L. and H. Kincaid. 1982. *Survival, growth, and catchability of rainbow trout of four strains.* N. Amer. J. Fish. Manag. 2(1): 1-10.

Brookes, A. 1990. *Restoration and enhancement of engineered river channels: some European experiences.* Regulated Rivers: Research & Management 5(1): 45-56.

Brynildson, W.C. and J. Truog. 1960. *The methods adopted to prevent winterkill of fish in Cox Hollow Lake, Iowa County, during the winter of 1960.* Wisconsin South Area Investigation Memo. No. 254, Wisconsin Cons. Dept. Madison, WI.

C.E. Jones and Associates Ltd. 1996. *Highland Valley Copper Annual Reclamation Report 1995. Reclamation Permits No. M-11 and M-55, Volume 2.* Report prepared for Ministry of Energy, Mines and Petroleum Resources.

Cherry, D.S. and R.K. Guthrie. 1975. *Significance of detritus or detritus-associated invertebrates to fish production in a new impoundment.* J. Fish. Res. Bd. Can. 32(10): 1799-1804.

Church, Michael, R.I. Ferguson and Rolf Kellerhals. (no date) *On the Relation of River Channel Gradient and Pattern to Discharge and Grain Size.* Unpublished draft report.

Coble, D.W. 1961. *Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos.* Trans. Am. Fish. Soc. 90(4): 469-474.

Cole, G.A. 1983. *TEXTBOOK OF LIMNOLOGY.* The C.V. Mosby Company, St. Louis, Toronto, London.

Cross, T.K. and R.C. Summerfelt. 1987. *Oxygen demand of lakes: Sediment and water column BOD.* Lake and Reservoir Manag. 3: 109-116.

Davis, J.C. 1975. *Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: A review.* J. Fish. Res. Bd. Can. 32(12): 2295-2332.

Demers, M.A., C.J. Tulman, J.W. Leggett and W.T. Westover. 1979. *Accelerated fisheries development program: Stream enhancement, Bill 5.* British Columbia Fish and Wildlife Br.

Dolloff, C.A., D. G. Hanlsin and G.H. Reeves. 1993. *Basinwide estimation of habitat and fish populations in streams.* General Technical Report SE-83, Southeastern Forest Experiment Station, P.O. Box 2680, Ashville, North Carolina 28802. 25 p.

Donald, D.B. and R.S. Anderson. 1982. *Importance of environment and stocking density for growth of rainbow trout in mountain lakes.* Rans. Amer. Fish. Soc. 111(6): 675-680.

Downing, J.A. and C. Plante. 1993. *Production of fish populations in lakes.* Can. J. Fish. Aquat. Sci. 50(1): 110-120.

Downing, J.A., C. Plante and S. Lalonde. 1990. *Fish production correlated with primary productivity, not the Morphoedephic Index.* Can. J. Fish. Aquat. Sci. 47(10): 1929-1936.

Dwyer, W.P. 1990. *Catchability of three strains of cutthroat.* N. Amer. J. Fish. Manag. 10(4): 458-461.

Elder, H. Y. 1965. *Biological effects of water utilization by hydro-electric schemes in relation to fisheries, with special reference to Scotland.* Proc. Royal Soc. Edinburgh, Sect. B, Vol. LXIX – Part III (No.4): 245-271.

Everest, F.H., R.L. Beschta, J.C. Scrivener, K.V. Koski, J.R. Sedell and C.J. Cederholm. 1987. *Fine sediment and salmonid production: A paradox.* In: E.O. Salo and T.W. Cundy (eds.) Streamside management: Forestry and fishery interactions. College of Forest Res., Inst. of Forest Res. Pub. No. 57, Univ. of Washington, AR-10, Seattle, WA., 98195. p. 98-142.

Fast, A.W. 1973a. *Summertime artificial aeration increases winter oxygen levels in a Michigan lake.* Prog. Fish-Cult. 35(2): 82-84.

_____ 1973b. *Effects of artificial hypolimnion aeration on rainbow trout (Salmo gairdneri Richardson) depth distribution.* Trans. Am. Fish. Soc. 102(4): 715-722.

_____ 1994. *Winterkill prevention in lakes and ponds using artificial aeration.* Reviews in Fish. Sci. 2(1): 23-77.

Fast, A.W., V.A. Dorr and R.J. Rosen.1975. *A submerged hypolimnion aerator.* Water Resources Res. 11(2): 287- 299.

Fausch, K.D., C.J. Hawkes and M.G. Parsons. 1988. *Models that predict standing crop of stream fish from habitat variables: 1950-1985.* Gen. Tech Report PNW-GTR-213. U.S. Dept. of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Ore. 52 p.

Fay, C.W. and G.B. Pardue. 1986. *Harvest, survival, growth, and movement of five strains of hatchery-reared rainbow trout in Virginia streams.* N. Amer. J. Fish. Manag. 6(4): 569-579.

Flick, W. 1968. *Dispersal of aerated water as related to prevention of winterkill.* Prog. Fish-Cult. 30(1): 13-18.

Ford, B.S., P.S. Higgins, A.F. Lewis, K.L. Cooper, T.A.Watson, C.M. Gee, G.L. Ennis and R.L. Sweeting. 1995. *Literature reviews on the life history, habitat requirements and mitigation/compensation strategies for thirteen sport fish species in the Peace, Liard and Columbia River drainages of British Columbia. Canada.* Manuscr. Rep. Fish. Aquat. Sci. 2321. 342 p.

Fording Coal Ltd. 1991. *Henretta Dragline Project South and West Pits Volume 1 - Text.*

_____ 1992. *Henretta Dragline Pre-Development Activities and Fish and Fish and Wildlife Mitigation Works.*

_____ 1994. *Henretta Dragline Development and South Spoil Development Fish and Wildlife Mitigation Works. Appendix III To Permit C-3 Annual Report for 1993.*

Garnas, E. and T. Hesthagen. 1982. *The population of brown trout (Salmo trutta L.) in some regulated lakes in southern Norway.* Rep. Inst. Freshwater Res., Drottningholm. 60: 25-30.

Garrell, M.H., J.C. Confer, D. Kirschner and A.W. Fast. 1977. *Effects of hypolimnetic aeration on nitrogen and phosphorus in a eutrophic lake.* Water Resources Res. 13(2): 343-347.

Greenbank, J.T. 1945. *Limnological conditions in ice-covered lakes, especially as related to winterkill of fish.* Ecol. Monogr. 15: 343-392.

Grimas, U. 1961. *The bottom fauna of natural and impounded lakes in northern Sweden (Ankarvattnet and Blasjon).* Rep. Inst. Freshwater Res. Drottningholm 42: 183-237.

_____ 1962. *The effect of increased water level fluctuation upon the bottom fauna in Lake Blasjon, northern Sweden.* Rep. Inst. Freshwater Res. Drottningholm 44: 14041.

_____ 1964. *Studies on the bottom fauna of impounded lakes in southern Norway.* Rep. Inst. Freshwater Res. Drottningholm 45: 94-104.

_____ 1965. *The short-term effect of artificial water-level fluctuations upon the littoral fauna of Lake Kultsjon, northern Sweden.* Rep. Inst. Freshwater Res. Drottningholm 46: 5-21.

Halsey, T.G. 1968. *Autumnal and over-winter limnology of three small eutrophic lakes with particular reference to experimental circulation and trout mortality.* J. Fish. Res. Bd. Can. 25(1): 81-99.

Halsey, T.G. and D.M. Galbraith. 1971. *Evaluation of two artificial circulation systems used to prevent trout winterkill in small lakes.* B.C. Fish and Wildl. Br., Fish. Manag. Publ. No. 16.

Halsey, T.G. and S.J. MacDonald. 1971. *Experimental trout introduction and artificial circulation of Yellow Lake, British Columbia.* Brit. Col. Fish and Wildl. Br., Fish. Manag. Rep. No. 63.

Hamaguchi, B. 1997. *Highland Valley Copper's trophy fishery.* The 99th Annual Conference of the Canadian Institute of Mining, Metallurgy and Petroleum, April 27-30, Vancouver, B.C. 17 p.

Hardy BBT Ltd. 1990. *Guidelines for the design and construction of stream channels for Yukon placer mined streams (Second Edition).* Report prepared for Habitat Management Division, Pacific Region, Fisheries and Oceans Canada. 86 p.

Harris, B. 1999. *Burnell Lake: The pipe dream comes.* B.C. Outdoors 55(4): 53-56.

Hartman, G.F. 1969. *Reproductive biology of the Gerrard stock rainbow trout, p. 53-67.* In: T.G. Northcote (ed.) Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, Institute of Fisheries, University of British Columbia. 388 p.

Hartman, G.F. and D.M. Galbraith. 1970. *The reproductive environment of the Gerrard stock rainbow trout.* B.C. Fish and Wildl. Br., Fish. Manag. Rep. Series, No. 15. 51 p.

Hartman, G.F. and M. Miles. 1995. *Evaluation of fish habitat improvement projects in B.C. and recommendations on the development of guidelines for future work.* Prepared for Fisheries Branch, B.C. Ministry of Environment, Lands and Parks. 40 p plus appendices.

Hartman, G.F., T.G. Northcote and C.C. Lindsey. *1962. Comparison of inlet and outlet spawning runs of rainbow trout in Loon Lake, British Columbia.* J. Fish. Res. Bd. Can. 19(2): 173-200.

Hartman G.F. and J.C. Scrivner. 1990. *Impacts of Forestry Practices on a Coastal Stream Ecosystem, Carnation Creek, British Columbia.* Can. Bull. Fisheries and Aquatic Sciences. 223.

Hatfield Consultants Ltd. 1997. *Rainbow Trout, Benthic Invertebrate, and Sediment Quality Monitoring Program at Highland Valley Copper 1996.* Unpublished report prepared for Highland Valley Copper, Logan Lake, B.C.

_____ 1998. *Rainbow Trout, Benthic Invertebrate, and Sediment Quality Monitoring Program at Highland Valley Copper 1997.* Unpub. report prepared for Highland Valley Copper, Logan Lake, B.C.

Hazzard, L.K. 1968. *Winterkill studies; Lajara and Road Canyon No. 1 reservoirs; 1966-1968.* Colorado Game, Fish and Parks Dept., Denver, CO.

Hecky, R.E. and G.K. McCullough. 1984. *Effect of impoundment and diversion on the sediment budget and nearshore sedimentation of Southern Indian Lake.* Can. J. Fish. Aquat. Sci. 41(4): 567-578.

Hecky, R.E., R.W. Newbury, R.A. Bodaly, K. Patalas and D.M. Rosenberg. 1984. *Environmental impact prescription and assessment: The Southern Indian Lake experience.* Can. J. Fish. Aquat. Sci. 41(4): 720-732.

Hey, R.D. and G.L. Heritage. 1993. *DRAFT GUIDELINES FOR THE DESIGN AND RESTORATION OF FLOOD ALLEVIATION SCHEMES.* National Rivers Authority, Bristol, England.

Highland Valley Copper. 1994. *HIGHLAND VALLEY COPPER: Bethlehem Water Management Plan.* Unpublished report.

Hogan, D.L., S.A. Bird and D.J. Wilford. 1996. *Channel Conditions and Prescriptions Assessment (Interim Methods).* Watershed Restoration Technical Circular No. 7. B.C. Ministry of Environment, Lands and Parks. 42 p.

Holtby, L.B. and M.C. Healey. 1986. *Size selection for adult size in female coho salmon (Oncorhynchus kisutch).* Can. J. Fish. Aquat. Sci. 43(10): 1946-1959.

Holtby, L.B. and J.C. Scrivener. 1989. *Observed and simulated effects of climate variability, clear-cut logging and fishing on the numbers of chum salmon (Oncorhynchus keta) and coho salmon (O. kisutch) returning to Carnation Creek, British Columbia, p. 62-81.* In: C.D. Levings, L.B. Holtby and M.A. Henderson (eds.). Proc. of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks, Can. Spec. Publ. of Fish. Aquat. Sci. 105.

Hume, J.M. and K. Tsumura. 1992. *Field evaluation of two rainbow trout strains introduced into three British Columbia lakes.* N. Amer. J. Fish. Manag. 12(3): 465-473.

Jenkins, R.M. 1967. *The influence of some environmental factors on standing crop and harvest of fishes in U.S. reservoirs.* In: Proc Reservoir Fisheries Symp., Southern Div. Amer. Fish Soc. p. 298-321

_____ 1982. *The morphoedaphic index and reservoir fish production.* Trans. Am. Fish. Soc. 111(2): 133-140.

Jones, J.B. and P.J. Mulholland. 2000. *Streams and Ground Waters.* Academic Press, San Diego, San Francisco, New York. 425p.

Johnson, R. and J. Skrypek. 1975. *Prevention of winterkill of fish in a southern Minnesota lake through use of a helixor aeration and mixing system.* Minnesota Department of Natural Resources, Div. Of Fish and Wildl., Section of Fisheries, Investigational Report No. 336.

Johnston, N.T. and P.A. Slaney. 1996. *Fish Habitat Assessment Procedures.* Watershed Restoration Technical Circular No. 8. B.C. Min. of Environment, Lands and Parks and Min. of Forests. 97 p.

Kellerhals, R. 1982. *Effect of River Regulation on Channel Stability.* In: *GRAVEL-BED RIVERS: Fluvial Processes, Engineering and Management.* R.D. Hey, J.C. Bathurst, C.R. Thorne [Eds.] John Wiley & Sons Ltd. pp. 685-715.

Kellerhals, R. and M. Church. 1989. *The Morphology of Large Rivers: Characterization and Management.* In: D.P.Dodge, [ed.] Proceedings of the International Large Rivers Symposium. Canadian Special Pub. of Fisheries and Aquatic Sciences 106: 31-48.

Kellerhals, R. and M. Miles. 1996. *Fluvial Geomorphology and Fish Habitat: Implications for River Restoration.* In: Leclerc M. et al. [edit.] Proceedings of the Second IAHR Symposium on Habitat Hydraulics, Ecohydraulics 2000, Quebec City, June 1996. pp. A261-279.

Kerr, S.R. 1982. *The Role of External Analysis in Fisheries Science.* Trans. Am. Fish. Soc. 111(2): 165-170

Korman, J., C.J. Perrin and T. Lekstrum. 1994. *A guide for the selection of standard methods for quantifying sportfish habitat capability and suitability in streams and lakes of B.C.* A discussion document prepared for B.C. Environment, Fisheries Branch, Research and Development Section, Vancouver, B.C. 87 p. and appendices.

Lackey, R.T. and D.W. Holmes. 1972. *Evaluation of methods of aeration to prevent winterkill.* Prog Fish-Cult. 34(3): 175-178.

Leach, J.H., L.M. Dickie, B.J. Shuter, U. Borgmann, J. Hyman and W. Lysack. 1987. *A review of methods for prediction of potential fish production with application to the Great Lakes and Lake Winnipeg.* Can. J. Fish. Aquat. Sci. 44(Suppl. 2): 471-485.

Lindsey, C.C., T.G. Northcote and G.F. Hartman. 1959. *Homing of rainbow trout to inlet and outlet spawning streams at Loon Lake, British Columbia.* J. Fish. Res. Bd. Can. 16(5): 695-719.

Line Creek Resources Ltd. 1992. *Line Creek Mine Annual Reclamation Report for 1992. Reclamation Permit C-129.* Submitted to Min. of Energy, Mines and Petroleum Resources.

_____ 1993. *Line Creek Mine Annual Reclamation Report for 1993. Reclamation Permit C-129.* Submitted to Min. of Energy, Mines and Petroleum Resources.

Lirette, M.G. and B.B. Chapman. 1993. *Winter limnological survey of selected lakes in central British Columbia, an assessment of winter kill risk.* Province of B.C., Ministry of Environment, Fisheries Branch, Williams Lake. B.C., Regional Fisheries Report No. CA 935.

Lloyd, D.S. 1987. *Turbidity as a water quality standard for salmonid habitats in Alaska.* N. Amer. J. Fish. Manag. 7(1): 34-45.

Lowe, Sheldon. 1992 *Fish Habitat Enhancement Structures.* Alberta Environmental Protection, Pisces Environmental Consulting Services Ltd. and Alberta Public works, Supply and Services.

Lulman, P.D. 1989. *Creating a Recreation Lake at TransAlta Utilities Whitewood Mine.* In: C.B. Powter, (ed.), Proc of Alberta Conservation and Reclamation Conf., September 22-23, 1988, Kananaskis, Alberta. pp. 57 - 62.

Luscar Ltd., Luscar–Sterco (1977) Ltd., Pisces Environmental Consulting Services Ltd. and Bighorn Environmental Design Ltd. 1994. *Development of sport fisheries in lakes created by coal mining operations in the eastern slopes. Final Report.* 151 p.

Mathias, J.A. and J. Barica. 1980. *Factors controlling oxygen depletion in ice-covered lakes.* Can. J. Fish. Aquat. Sci. 37(2): 185-194.

Merna. 1965. *Aeration of Winterkill Lakes.* Pro. Fish Cult. 27(4):1990202.

M. Miles and Associates Ltd. 1997. *Fisheries Habitat Project Success: SW Alberta, BC, Alaska, Oregon & Washington.* In: Proc. NO NET LOSS OF HABITAT: Assessing Achievement., Workshop sponsored by Fisheries and Oceans Canada, Richmond, B.C.

_____ 1999a. *Channel Stability Assessment: Theodosia River and Olsen Creek Diversion Channel: Compilation of Historical Air Photos.* Unpublished report prepared for Pacifica Papers Inc., Sechelt, B.C. 38 p.

_____ 1999b. *Channel Stability Analysis: Elk River, Crest Creek and Heber River: Compilation of Historical Air Photos.* Unpublished report prepared for B.C. Hydro and Power Authority, Burnaby.

Miles, Mike, Rolf Kellerhals and Gordon Hartman. 1999. *Future Priorities for Stream Restoration: Moving Beyond Sticks, Stones and Small Ponds.* Presented at In-Stream Restoration: Past Performance and Future Directions, BC Watershed Restoration Program Conference, UBC

Ministry of Fisheries. 1998a. *Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures.* Resource Inventory Committee, B.C. Ministry of Fisheries.

_____ 1998b. *Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Data Forms and User Notes.* Resource Inventory Committee, B.C. Ministry of Fisheries.

_____ 1998c. *Standards for Fish and Fish Habitat Maps.* Resource Inventory Committee, B.C. Ministry of Fisheries.

_____ 1999a. *Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Lake Survey Form Field Guide.* Resource Inventory Committee, B.C. Ministry of Fisheries. 27p.

Mitchell, D.F. 1982. *Effects of water level fluctuation on reproduction of largemouth bass, (Micropterus salmoides), at Millerton Lake, California, in 1973.* Cal. Fish and Game 68(2).

Newbury, R.W. and G.K. McCullough. 1984. *Shoreline erosion and restabilization in the Southern Indian Lake reservoir.* Can. J. Fish. Aquat. Sci. 41(4):558-565.

Newbury, Robert W. and Marc N. Gaboury. 1993. *STREAM ANALYSIS AND FISH HABITAT DESIGN: A Field Manual.* Newbury Hydraulics, Gibson, B.C. and Manitoba Natural Resources.

Newcombe, Charles P. and Jorgen O.T. Jensen. 1996. *Channel Suspended Sediment and Fisheries: A Synthesis for Quantitative Assessment of Risk and Impact.* North American Journal of Fisheries Management 16:693–727.

Nickum, J.G. 1970. *Limnology of winterkill lakes in South Dakota, p. 19-25.* In: E. Schneberger (ed.) A symposium on the management of midwestern winterkill lakes, Special Publ. North Central Div. Am. Fish. Soc.

Nilsson, –A. 1961. *The effect of water-level fluctuations on the feeding habits of trout and char in the Lakes Blasjon and Jormsjon, north Sweden.* Rep. Inst. Freshwater Res. Drottningholm 42: 238-261.

Northcote, T.G. 1980. *Morphometrically conditioned eutrophy and its amelioration in some British Columbia lakes, p.305-315.* In: J. Barica and L.R. Mur (eds.) Developments in Hydrobiology, Vol. 2. Published by W. Junk, The Netherlands.

_____ In press. *Impacts of impoundment: Comparative experience with fish communities, their food webs, productivity and problems in Canadian and Brazilian hydroelectric reservoir ecosystems.* Invited paper, Seminario Sobre Fauna Aquatica e o Setor Electrico Brasileiro, 10-12 April, 1996, Rio de Janeiro, Brasil. 46 p.

Northcote, T.G. and T.G. Halsey. 1969. *Seasonal changes in the limnology of some meromictic lakes in southern British Columbia.* J. Fish. Res. Bd. Can. 26(7): 1763-1787.

Northcote, T.G. and G.F. Hartman. 1988. *The biology and significance of stream trout populations (Salmo spp.) living above and below waterfalls.* Polskie Archiwum Hydrobiologii 35: 409-442.

Northcote, T.G. and P.A. Larkin. 1956. *Indices of productivity in British Columbia lakes.* J. Fish. Res. Bd. Can. 13(4): 515-540.

Oglesby, R.T. 1982. *The MEI symposium-overview and observations.* Trans. Am. Fish. Soc. 111(2): 171-175.

Pattenden, et al. 1998. *Can Instream Structures Effectively Restore Fisheries Habitat?* Forest-Fish Conference: Land Management Practices Affecting Aquatic Ecosystems. Canadian Forest Service, Northern Forestry Centre. Information Report NOR-X-356.

Petriarche, M.H. and J.W. Merna. 1970. *A resume of the winterkill problem, p. 7-17.* In E. Schneberger (ed.) A symposium on the management of midwestern winterkill lakes. Special Publ., North Central Div., Am. Fish. Soc.

Pennell, W. 1991. *Fish transportation handbook.* Province of British Columbia, Ministry of Agriculture and Fisheries. ISBN 0-7726-1274-9 (v.2).

Persons, W.R. and R.V. Bulkley. 1984. *Evaluation of the riverine cutthroat trout habitat suitability index model, p. 112-182.* In: J.W. Terrell (ed.) Proceedings of a workshop on fish habitat suitability index models. U.S. Dept. of Int., Fish and Wildl. Serv. Biol. Rep. 85(6). 393 p.

Poff, N. LeRoy and J.V. Ward. 1989. *Implications of Streamflow Variability and Predictability for Lotic Community Structure: A Regional Analysis of Streamflow Patterns.* Can. J. Fish Aquat. Sc. 46: 1805-1818.

Ptolemy, R.A. 1995. *Maximum salmonid densities in fluvial habitats in British Columbia.* In: J. Berg and P.W. Delaney [eds.] Proceedings of the Coho Workshop, May 26-28, 1992, Nanaimo, B.C. 382 p.

Puke, C. 1949. *The possibility of avoiding winterkill of fish.* Inst. Freshwater Res. Drottningholm, Report 31: 147-150.

Quintero, J.E. and J.E. Garton. 1973. *A low energy lake destratifier.* Trans. Am. Soc. Agr. Eng. 16(5): 1973-1978.

Raleigh, R.F., T. Hickman, R.C. Solomon and P.C. Nelson. 1984. *Habitat suitability information: rainbow trout.* U.S. Fish and Wildl. Service. Biol. Serv. Prog., FWS/OBS;82/10.60. 64 p.

Randall, R.G., C.K. Minns, V.W. Cairns and J.E. Moore. 1996. *The relationship between an index of fish production and submerged macrophytes and other habitat features at three littoral areas in the Great Lakes.* Can. J. Fish. Aquat. Sci. 53 (Suppl. 1): 35-44.

Rasmussen, D.H. 1960. *Preventing a winterkill by use of a compressed-air system.* Prog. Fish-Cult. 22(4): 185-187.

Rawson, D.S. 1951. *The total minteral content of lake waters.* Ecology 32(4): 669-672.

_____ 1952. *Mean depth and fish production of large lakes.* Ecology 33(4): 513-521.

_____ 1958. *Indices to lake productivity and their significance in predicting conditions in reservoirs and lakes with disturbed water levels, p. 27-42.* In: P.A. Larkin (ed.) The Investigation of Fish-power Problems, H.R. MacMillan Lectures in Fisheries, U.B.C., April 29 and 30, 1957.

Redfish Consulting Ltd. 1999. *Performance evaluation of six British Columbia kokanee spawning channels.* Prep. by Redfish Consulting Ltd., for British Columbia Conservation Foundation, Surrey, B.C. 52 p.

Richter, B.D., J.V. Baumgartner, R. Wigington and D.P. Braun. 1997. *How much water does a river need?* Special Applied Issues Section; Freshwater Biology 37: 231-249.

Rigler, F.H. 1982. *The relation between fisheries management and limnology.* Trans. Am. Fish. Soc. 111(2): 121-132.

Roads and Transportation Association of Canada [RTAC]. [C.R. Neill, ed.] 1973. *GUIDE TO BRIDGE HYDRAULICS*. University of Toronto Press, Toronto. 191 pp.

_____ 1980 *METRIC SUPPLEMENT TO THE GUIDE TO BRIDGE HYDRAULICS*

Runnstrom, S. 1951. *The population of char in a regulated lake.* Rep. Inst. Freshwater Res. Drottningholm 32: 67-78.

Runnstrom, S. 1955. *Changes in fish production in impounded lakes.* Proc. Int. Ass. Theor. Appl. Limnol. Vol. XII: 176-182.

Ryder, R.A. 1965. *A method for estimating the potential fish production of north-temperate lakes.* Trans. Am. Fish. Soc. 94(3): 214-218.

_____ 1982. *The morphoedaphic index - use, abuse and fundamental concepts.* Trans. Am. Fish. Soc. 111(2): 154-164.

Ryder, R.A., S.R. Kerr, K.H. Loftus and H.A. Regier. 1974. *The morphoedaphic index, a fish yield estimator – review and evaluation.* J. Fish. Res. Bd. Can. 31(5): 663-688.

Schlesinger D.A. and H.A. Regier. 1982. *Climatic and morphoedaphic indices of fish yields from natural lakes.* Trans. Am. Fish. Soc. 111:141-150.

Schoenecker, W. 1970. *Management of winterkill lakes in the Sandhill region of Nebraska, p. 53-56.* In E. Schneberger (ed.) A symposium on the management of midwestern winterkill lakes. Special Publ., North Central Div., Am. Fish. Soc.

Schumm, Stanley A. 1977. *THE FLUVIAL SYSTEM.* John Wiley and Sons Inc. Toronto, Canada. 338 p.

Scott, W.B. and E.J. Crossman. 1973. *Freshwater Fishes of Canada.* Bulletin Fisheries Research Board. Can. 184. 966 p.

Selbig, W. 1970. *Chemical Rehabilitation of Chronic Winterkill Lakes. p. 27-30.* In E. Schneberger (ed.) A symposium on the management of midwestern winterkill lakes. Special Publ., North Central Div., Am. Fish. Soc.

Shrubsole, Dan. 1994. *'NATURAL' CHANNEL DESIGN: Perspectives and Practice.* Proc. First International Conference on Guidelines for 'Natural' Channel Systems. Niagara Falls, Ontario.

Sidney, M.H. 1984. *Kamloops lake aeration: Final report.* Fish and Wildlife Branch, Region 3. 24 p.

Sidney, M.H. 1991. *Lake aeration project evaluation: Project completion report, Habitat Conservation Fund 1989–1990.* Region 3, Thompson-Nicola Sub-region, Fisheries Branch, Kamloops, B.C. 21 p.

Slaney, P.A. and D. Zaldokas. 1997. *Fish Habitat Rehabilitation Procedures.* Watershed Restoration Circular No. 9. B.C. Ministry of Environment, Lands and Parks.

Smith, S.A., D.R. Knauer and T.R. Wirth. 1975. *Aeration as a lake management technique.* Wisconsin Dep. Nat. Resources, Tech. Bull. No. 87.

Soltero, R.A., L.M. Sexton, K.I. Ashley and K.O. McKee. 1994. *Partial and full lift hypolimnetic aeration of Medical Lake, WA to improve water quality.* Wat. Res. 28(11): 2297-2308.

Sowden, T.K. and G. Power. 1985. *Prediction of rainbow trout embryo survival in relation to groundwater seepage and particle size of spawning substrates.* Trans. Am. Fish. Soc. 114(6): 804-812.

Stables, T.B., G.L. Thomas, S.L. Thiesfeld, G.B. Pauley. 1990. *Effects of reservoir enlargement and other factors on the yield of wild rainbow and cutthroat trout in Spade Lake, Washington.* North Am. J. Fish. Manag. 10(3): 305-314.

Stoneman, C.L., M.L. Jones and L. Stanfield. 1996. *Habitat suitability assessment models for southern Ontario trout streams.* Model development and evaluation. Can. Man. Rep. Fish Aquat. Sci. 2345. 45 p.

Summerfelt, R.C. 1983. *Management of winterkill lakes with artificial aeration, p. 203-208.* In: C.R. Berry, Jr. (ed) Proceedings Bonneville Chapter, Am. Fish. Soc., Bethesda, MD.

Summerfelt, R.C and T.K. Cross. 1983. *Artificial destratification to prevent winterkill: Completion Report.* Iowa State Water Resources Research Institute, Iowa State University, Submitted to the US Department of the Interior, Washington, DC. 83 p.

Summerfelt, R.C., B.R. Holt and A.K. McAlexander. 1980. *Fall and winter aeration of lakes by mechanical pumping to prevent fish kills, p. 933-942.* In: Proceedings of the symposium on surface water impoundments ASCE, June 2-5, 1980, Minneapolis, Minnesota.

Tabor, R.A. and W.A. Wurtsbaugh. 1991. *Predation risk and the importance of cover for juvenile rainbow trout in lentic systems.* Trans. Amer. Fish. Soc. 120(6): 728-738.

Taylor, G.D. (no date). *Proposals and progress reports relative to fish enhancement at Eighty-three Creek near 70 Mile House, B.C., April 28, 1969 to July 31, 1971.* Unpubl. Rep., Hab. Improv. Sect., Fish and Wildl. Br., Victoria, B.C.

Teraguchi, M. and T.G. Northcote. 1966. *Vertical distribution and migration of Chaoborus flavicans larvae in Corbett Lake, British Columbia.* Limnol. Oceanog. Vol.2(2): 164-176.

Terrell, J.W. and J.G. Nickum. 1984. *Workshop synthesis and recommendations, p. 1-16.* In: J.W. Terrell (ed.) Proceedings of a workshop on fish habitat suitability index models. U.S. Dept. of Int., Fish and Wildl. Serv. Biol. Rep. 85(6). 393 p.

Thurston, R.V., G.R. Phillips, R.C. Russo and Hinkins. 1981. *Increased toxicity of ammonia to rainbow trout (Salmo gairdneri) resulting from reduced concentrations of dissolved oxygen.* Can. J. Fish. Aquat. Sci. 38(8): 983-988.

Tsumura, K. and V.E. Blann. 1988. *Fishery development in barren, winterkill lakes.* Fish. Tech. Circ. No. 80, Province of British Columbia, Ministry of Environment and Parks. 8 p.

Tsumura, K., J.M. Hume and B.M. Chan. 1987. *Effects of size at release in rainbow trout (Salmo gairdneri) stocked in a winterkill lake.* Fish. Manag. Rept. No. 88, Province of British Columbia, Ministry of Environment and Parks. 15 p.

U.S. Army Corps of Engineers, et al. 1999. *STREAMBANK STABILIZATION HANDBOOK.* Distributed by Veri-Tech Inc @ www.veritechinc.com. 500 p.

U.S. Government. 1998. *STREAM CORRIDOR RESTORATION: Principles, Processes, and Practices.* The Federal Interagency Stream Restoration Working Group.

Wedemeyer, G.A. 1996. *Transportation and handling, p. 727-758.* In: W. Pennell and B.A. Barton (eds.) Principles of salmonid culture: Developments in aquaculture and fisheries science, Vol. 29. Elsevier, Amsterdam, Lausanne, New York.

Welch, P. 1952. *LIMNOLOGY.* McGraw-Hill Book Company, Inc., New York, Toronto and London.

Wirth, T.L. 1970. *Mixing and aeration systems in Wisconsin lakes, p.31-46.* In: E. Schneberger (ed.) A symposium on the management of midwestern winterkill lakes. Special Publ., North Central Div., Am. Fish. Soc.

Witzel,L.D. and H. R. MacCrimmon. 1981. *Role of gravel substrate on ova survival and alevin emergence of rainbow trout, Salmo gairdneri.* Can. J. Zool. 59(4): 629-636.

Youngs, W.D. and D.G. Heimbuch. 1982. *Another consideration of the morphoedaphic index.* Trans. Am. Fish. Soc. 111(2): 151-155.

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TABLE 1: WATER QUALITY REQUIREMENTS FOR RAINBOW TROUT

PARAMETER	RECOMMENDED VALUE	COMMENT
Oxygen	"near saturation" 14.62 mg/L @ 0°C 11.29 mg/L @ 10°C 9.09 mg/L @ 20°C 7.56 mg/L @ 30°C	■ solubility is temperature dependent. ■ ammonia toxicity decreases with increasing O_2.
pH	6.0 to 9.0 range	■ low pH causes coagulation of gill mucus and reduces oxygen transport capacity. ■ low pH may increase the toxicity of heavy metals.
Ammonia	$[NH_3 + NH_4]$ 0.08 to 2.5 mg/L range *(see Table A1.4.1)*	■ effects of pH, temperature and ammonia are interdependent, e.g. • ≤ 2.00 mg/L @ 0 °C and pH 6.5. • ≤ 0.08 mg/L @ 30°C and pH 9.0.
Heavy Metals	varies with element (e.g. 0.05 mg/L for zinc to 25 mg/L for nickel)	■ toxicity varies with O_2 concentration, pH and water hardness. ■ toxicities of heavy metals may be additive.
Iron	< 0.3 mg/L	■ iron hydroxide precipitate interferes with gill function through occlusion of the gill lamellae.
Suspended Sediment	< 25 mg/L	■ adverse biological effects of suspended sediment reflect both concentration and duration(and, possibly, particle size).
Selenium	0.05 mg/L	■ criteria are currently under review. Selenium may bio-accumulate.

TABLE 2: SUCCESS SUMMARY, LAKE AERATION PROJECTS

MOELP REGION	LOCATION	SUCCESS				COMMENTS
		FAILURE	LIMITED	MODERATE	OUTSTANDING	
KAMLOOPS	Logan Lake				X	
	Walloper Lake				X	
	Lodgepole Lake				X	
	Horseshoe Lake				X	
	Stake Lake				X	
	Bleeker Lake				X	
	Tulip Lake				X	
	Rose Lake				X	
KOOTENAY	Stoney Lake	X				diesel generator and diffusers
	Johnson Lake			X		pH high, low fish survival
	Campbell Lake	X				hydrovane recirculator
	Wapiti Lake	X				solar power
WILLIAMS LAKE	Irish Lake				X	
	Dewar Lake				X	trout production impacted by shiners
	Higgins Lake				X	
	Skulow Lake			X		trout production impacted by shiners
PRINCE GEORGE	Inga Lake				X	
	Sundance Lake			X		
	Beaver Lake	X				
PENTICTON	Yellow Lake				X	trout production impacted by perch
	Gardom Lake				X	
	Kidd Lake				X	
	Burnell Lake				X	
	Lady King Lake				X	
	Martins Lake				X	
SUB-TOTAL		4	–	3	18	
% OF TOTAL PROJECTS (25)		16	0	12	72	

TABLE 3: SUCCESS SUMMARY, LAKE LEVEL AND FLOW PROJECTS

REGION	LOCATION	PROJECT TYPE			SUCCESS				COMMENTS
		LAKE LEVEL ONLY	LAKE LEVEL & FLOW	NEW LAKE	FAILURE	LIMITED	MODERATE	OUTSTANDING	
KAMLOOPS	Johnson Lake	X							Success Level Unknown
	Peter Hope Lake	X						X	
	Beaverhouse Lake		X				X		
	Walloper Lake		X					X	
	Isabele Lake		X					X	
	Joyce Lake		X					X	
	Trojan Pond	X						X	Former tailings pond constructed by Highland Valley Copper.
WILLIAMS LAKE	Fletcher Lake	X						X	
	Tete Angela Creek	X					X		
	Bringham Dam (Dog Creek)	X				X			
	Nina Lake	X						X	
	Morehead Lake	X				X			
	Puntzi Lake	X							Success Level Unknown
	Bootjack Lake	X							Success Level Unknown
	Polly Lakes	X							Success Level Unknown
PRINCE GEORGE	Shesta Lake	X			X				
	Inga Lake	X					X		
PENTICTON	Echo Lake	X					X		
	Kidd Lake	X						X	
	Rampart Lake	X							Success Level Unknown
	Harvey Hall Lake	X			X				
	Burnell Lake		X					X	
ALBERTA	Lac Des Roche			X		X			
	Lovett Lake			X			X		
	Silkstone Lake			X			X		
	East Pit Lake			X				X	
	Forestburg Diplomat Mine Lake			X				X	
	Black Nuggett Pond			X			X		
TOTAL		17	5	6	2	3	7	11	
% OF 23 RATED PROJECTS					9	13	30	48	

TABLE 4: SUCCESS SUMMARY, SPAWNING AND REARING CHANNEL PROJECTS

REGION	LOCATION	PROJECT OBJECTIVE		DESCRIPTION	DESIGN COMPLEXITY	SUCCESS				COMMENTS
		SPAWNING ONLY	SPAWNING & REARING			FAILURE	LIMITED	MODERATE	OUTSTANDING	
KAMLOOPS	Criss Creek	X		Gravel platform	2	X				
	Shaken Creek	X		Gravel platform	2	X				
	Johnson Lake			Access structures	7					Fish Way, success unknown
	Lac de Roche	X		Spawning channel	5				X	Pumped to control channel Fry recruited
	Dutch Lake	X		Spawning channel	5				X	Pumped to control channel Fry recruited
	Lac La Jeune	X		Spawning channel	5				X	Pumped to control channel Eggs/fry killed
	Roche Lake	X		Spawning channel	5				X	Pumped to control channel Eggs/fry killed
	Logan Lake	X		Spawning channel	5				X	Pumped to control channel Eggs/fry killed
	Trojan Lake 1	X		Spawning channel	5	X				Pumped to control channel Highland Valley Copper
	Trojan Lake 2		X	Spawning channel	4	X				Highland Valley Copper
	Trojan Lake 3		X	Spawning channel & cover	7				X	
KOOTENAY	Staples Creek	X		Gravel placement	1				X	
	Lavington Creek		X	Gravel placement & cover	3	X				
	Hall Lake	X		Gravel placement	1			X		
	Connors Lake	X		Gravel platforms	2			X		
	Whiteswan Lake	X		Spawning channel	6			X		
WILLIAMS LAKE	Fletcher Lake	X		Gravel platform	2				X	
	Eureka Creek (outlet)	X		Gravel placement	1			X		
	Chaunigan Creek	X		Gravel placement	1		X			
	Watch Creek	X			?		X			
	Dog Creek	X		Gravel placement	1	X				
	Holley & Hallis Creeks	X		Gravel platforms	2		X			
	Little Horsefly River	X		Gravel scarify & placement	2					Kokanee, success unknown
	Chimney Lake (inlet & outlet)	X		Gravel placement	1			X		
	Bridge Lake (outlet)	X		Gravel placement	1	X				
	Morshead Lake	X		Gravel placement	1	X				
	83 Creek	X		Spawning channel	6	X				

TABLE 4 - continued: SUCCESS SUMMARY, SPAWNING AND REARING CHANNEL PROJECTS

REGION	LOCATION	PROJECT OBJECTIVE		DESCRIPTION	DESIGN COMPLEXITY	SUCCESS				COMMENTS
		SPAWNING ONLY	SPAWNING & REARING			FAILURE	LIMITED	MODERATE	OUTSTANDING	
SMITHERS	Silverthorn Creek	X		Gravel placement & culvert removal	2			X		
	Island Lake (outlet)	X		Gravel placement	1					Success unknown
	Helene Lake (outlet)	X		Gravel placement	1				X	
	Nadina River	X		Spawning channel	4			X		
	Bertok Creek (outlet)	X		Gravel placement	1		X			
	Tagetochlain Creek (outlet)	X		Gravel placement	1			X		
	Lakelse Lake (inlet)	X		Gravel placement in 4 small tributaries	1		X			
	Seeley Creek	X		Gravel placement & beaver dam removal	1	X				
	Chicken Creek (lower)	X		Gravel placement	1	X				
	Chicken Creek (upper)	X		Gravel placement	1	X				
PRINCE GEORGE	Purden Lake (outlet)	X		Gravel placement	1					Success unknown
	Corkscrew Creek	X		Gravel platform	2	X				
	Bateman Creek	X		Gravel platform	2		X			
	Inga Lake	X		Spawning channel	5				X	Pumped to control channel Eggs/fry killed
	Chubb Lake	X		Spawning channel (between Chubb and an upper lake)	4	X				
PENTICTON	Winfield Creek	X		Gravel placement	1		X			Kokanee
	Middle Vernon Creek	X		Gravel placement, filter cloth and rip-rap	3				X	Kokanee
	Mission Creek **		X	Spawning channel & cover	7	X				Kokanee and Rainbow
	Peachland Creek	X		Gravel platform & sediment control	3				X	Kokanee and Rainbow
	Penticton Creek	X		Gravel placement	1		X			Kokanee
	Trepanier Creek	X		Gravel placement	1		X			
	Powers Creek	X		Gravel platform	2		X			Kokanee
ALBERTA	Lac Des Roche		X	Outlet channel in man-made lake	7		X			
	Lovett Lake		X	Outlet channel in man-made lake	7	X				
TOTAL		44	6			16	11	8	12	
% OF 47 RATED PROJECTS						34	23	17	26	

Notes: ** see Section A6.8

TABLE 5: SUCCESS SUMMARY, ECOLOGICALLY EFFECTIVE DIVERSION CHANNELS

PROVINCE OR TERRITORY	LOCATION	CHANNEL CONSTRUCTED AROUND				SUCCESS				COMMENTS
		PIT	ROCK DUMP	POND	ROAD	FAILURE	LIMITED	MODERATE	OUTSTANDING	
BRITISH COLUMBIA	South Line Creek Line Creek Coal Mine		X			X				
	Line Creek Line Creek Coal Mine				X			X		
	Fording River Fording Coal Ltd.				?		X			
	Henretta Creek Fording Coal Ltd.	X								Channel may not yet be built.
	Waste Rock Creek Kemess Mine		X							Channel not yet constructed.
YUKON	North Fork, Rose Creek Faro Mine	X				X				Channel eroded
	Rose Creek Faro Mine			X			X			
ALBERTA	Sphinx Creek Cardinal R. Coals Ltd.	X				X				Stream unpassable in culvert
	Upper Sphinx Creek Cardinal R. Coals Ltd.			X			X			
	Centre Creek Coal Valley Mine	X							X	
NWT	BHP Minerals Ekati Diamond Mine	X						X		
SUB-TOTAL		5	2	2	2	3	3	2	1	
% OF 9 RATED PROJECTS						33	33	22	11	

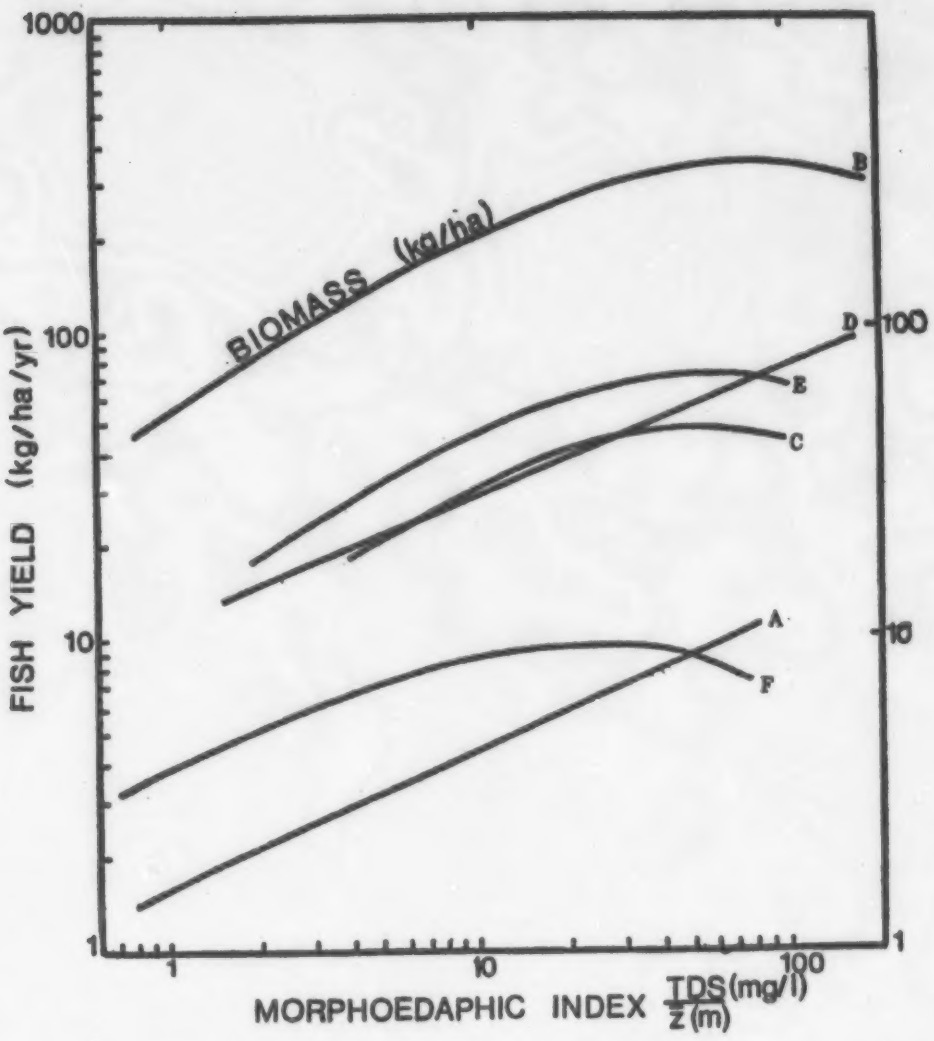

Figure 1: Yield and/or biomass curves for four regional lake groups: A, yield for north-temperate lakes of North America; B, biomass curves for temperate and south-temperate reservoirs of USA; C, yield curve for reservoirs *from Jenkins (1967)*; D, yield curve for tropical African lakes; E, yield curves from African lakes using model *from Jenkins (1967)*; and F, yield curve for north-temperate lakes of Finland. Figure *from Ryder, et al. (1974)*. See *Ryder, et al. (1974)* for more details about this figure.

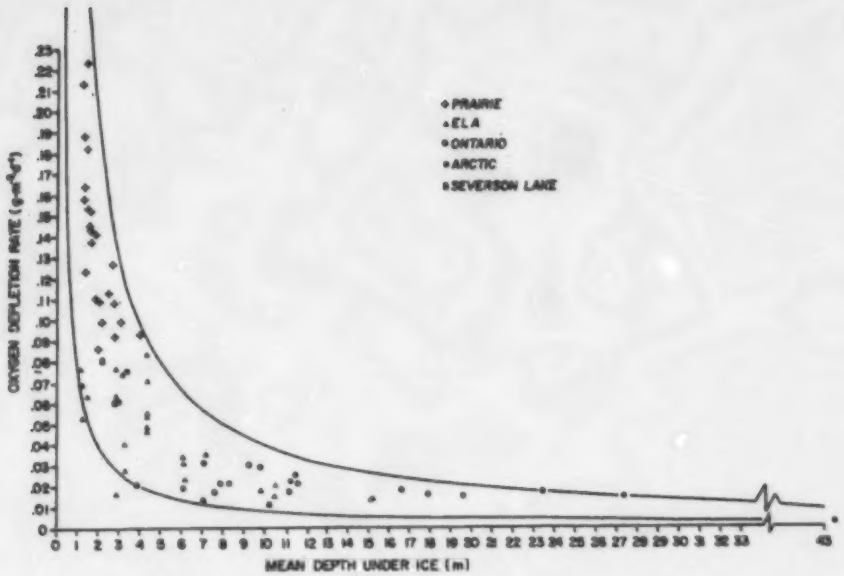

Figure 2: Rate of oxygen depletion during winter as a function of mean depth of the lake (as corrected for ice thickness). For comparison, lines indicate the loci of lakes whose area-based respiration rates are constant at 0.40 g 0_2 $m^{-3}d^{-1}$ (upper line) and 0.80 g 0_2 $m^{-3}d^{-1}$ (lower line) *(from Mathias and Barica, 1980)*.

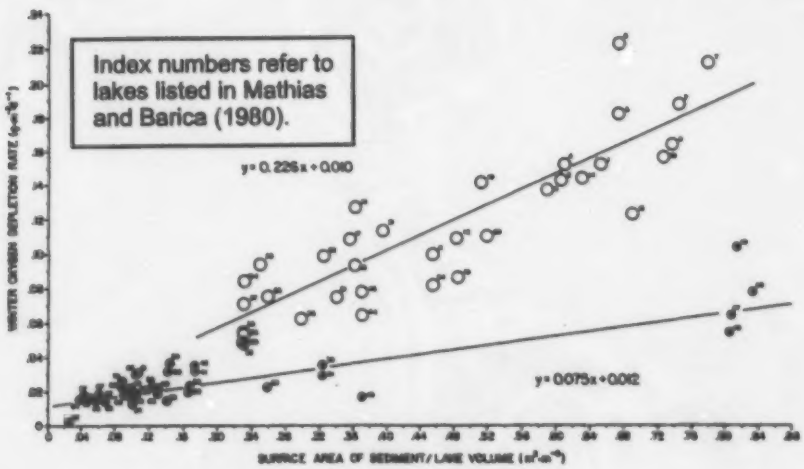

Figure 3: Relationship between the rate of oxygen depletion during winter and the sediment area:lake volume ratio. The upper line represents eutrophic lakes and the lower line represents oligotrophic lakes *(from Mathias and Barica, 1980)*.

Figure 4(I)
Date: July 31, 1948
BC675 #69

NOTE:

- Pre-logging channel conditions.

Discharge:

Theodosia River Near Bliss Landing	na
Roberts Creek at Roberts Creek	na

Figure 4(II)
Date: June 9, 1960
BC5015 #14

NOTE:

- Road and bridge construction.
- Widespread logging with no riparian leave buffers.
- Increased instability and sediment production at O, P, Q, R and S.
- Increased channel shifting, greater channel widths and enlarged instream sediment accumulations along logged sections of Theodosia River.

Discharge:

Theodosia River Near Bliss Landing	na
Roberts Creek at Roberts Creek	0.212 m^3/s

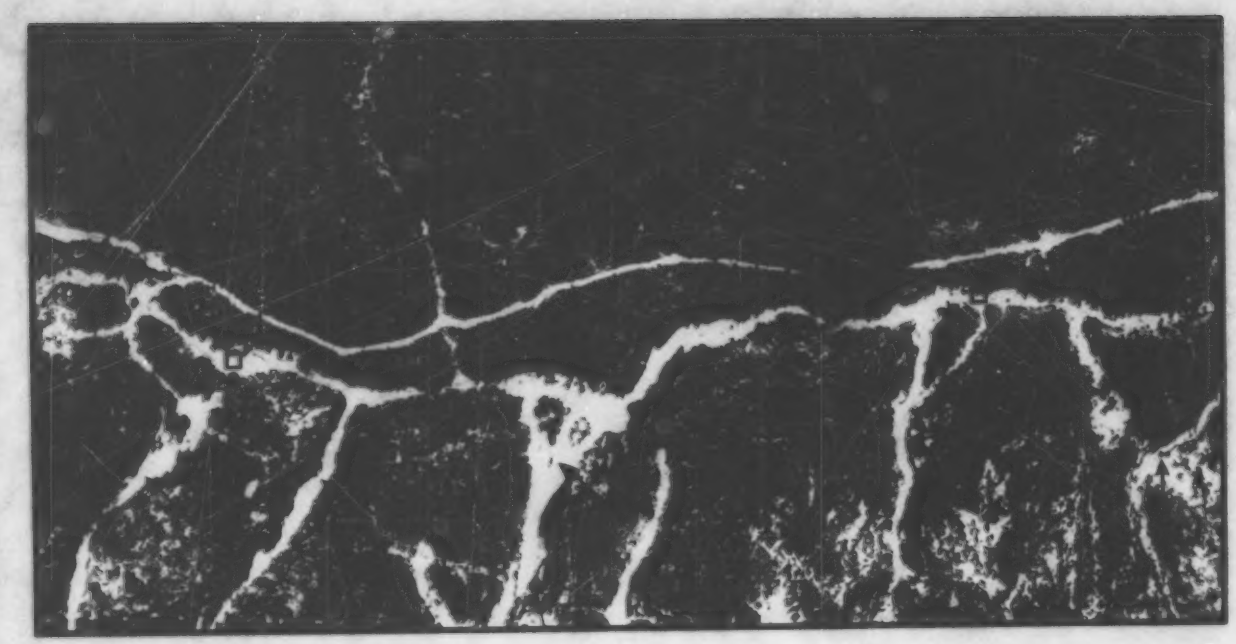

Figure 4(III)
Date: July 29, 1965
BC4331 #44

NOTE:

- Widespread slope instabilities at J, O, P, Q, R, S, T, U and V which have transported sediment into Theodosia River.
- Increased channel instability and enlarged sediment accumulations between K and W.

Discharge:

Theodosia River Near Bliss Landing	0.323 m^3/s
Roberts Creek at Roberts Creek	0.071 m^3/s

☐ Kilometer Marks

Figure 4A: Historical changes in channel morphology, Theodosia River (B.C.) Km 20 to 19 *(from M. Miles and Associates Ltd., 1999a)*.

Figure 4(iv)
Date: July 24, 1978
30BC78124 #10

NOTE:

- Widespread revegetation and slope stabilization.
- New clearcut at X.
- Continued presence of enlarged instream sediment accumulations.

Discharge:

Theodosia River Near Bliss Landing	0.249 m^3/s
Roberts Creek at Roberts Creek	0.074 m^3/s

Figure 4(v)
Date: July 19, 1988
30BC88025 #154

NOTE:

- General decrease in channel width and increase in channel stability as the riparian vegetation matures.

Discharge:

Theodosia River Near Bliss Landing	2.160 m^3/s
Roberts Creek at Roberts Creek	0.128 m^3/s

Figure 4(vi)

Date: September 12, 1998

MBC98006 #19 & #21

NOTE:

- Further increase in channel stability and continued reduction in the size of instream sediment accumulations.

Discharge:

Theodosia River Near Bliss Landing	na
Roberts Creek at Roberts Creek	0.058 m^3/s

☐ Kilometer Marks

Figure 4B: Historical changes in channel morphology, Theodosia River (B.C.) Km 20 to 19 *(from M. Miles and Associates Ltd., 1999a)*.

Figure 5(I)
Date: August 23, 1931
A4059 #38

NOTE:

- Extensive valley flat vegetation.
- Channel width.
- Extent of unvegetated gravel accumulations in the vicinity of F and G.

Discharge:

Gold River Below Ucona River — **ns**

Figure 5(II)
Date: May 30, 1957
BC2095 #38

NOTE:

- Road construction and channel encroachment at H and I.
- Widespread clearcutting with no riparian buffers.
- Growth of deciduous vegetation adjacent to the river channel in areas of clearcut.
- Bank erosion, channel shifting, increased unvegetated channel width and enlarged sediment accumulations in the vicinity of F and G.

Discharge:

Gold River Below Ucona River — **57.2 m^3/s**

Figure 5(iii)
Date: August 6, 1966
BC5208 #113 & #111

NOTE:

- Transmission Line Right-of-Way constructed at J.
- Road constructed on right bank with river encroachments at K and L.
- New river encroachment at M.
- Massive bank erosion, channel shifting and deposition of eroded sediment in the vicinity of F and G.

Discharge:

Gold River Below Ucona River — 57.2 m^3/s

Figure 5(iv)
Date: April 2, 1970
42773

NOTE:

- Additional channel shifting and movement of gravel bars in the vicinity of F and G.
- Increase in the size of the gravel bars at M.

Discharge:

Gold River Below Ucona River — 26.3 m^3/s

☐ Kilometer Marks

Figure 5A: Historical changes in channel morphology on Elk River, B.C., Km 6 to 5 *(from M. Miles and Associates Ltd., 1999b).*

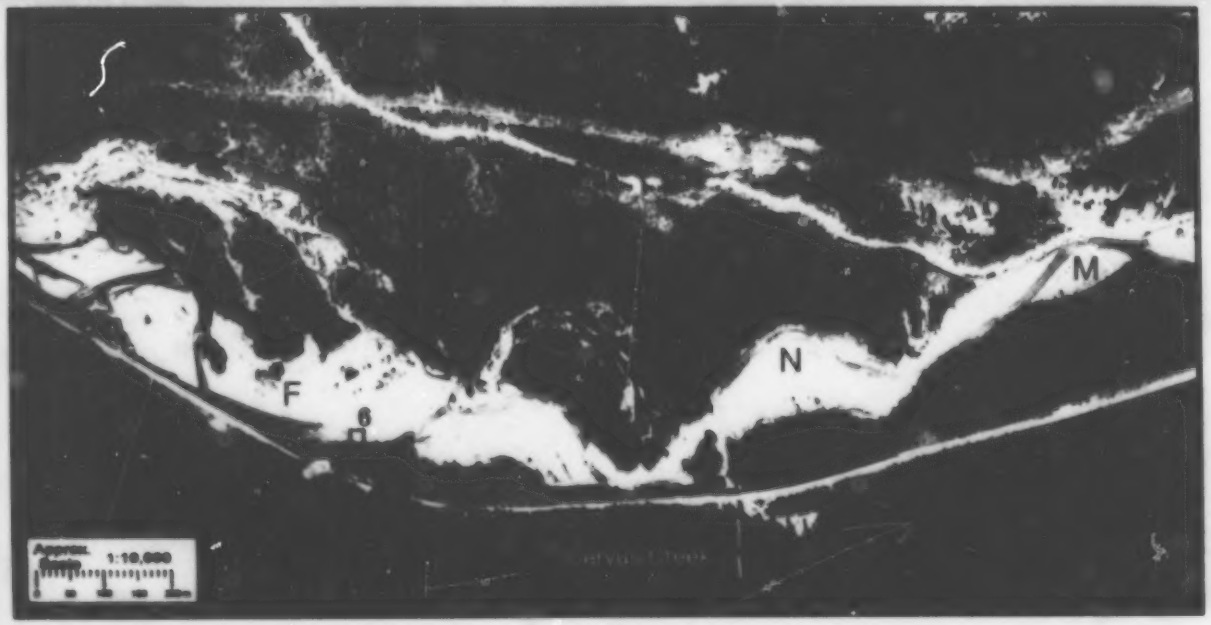

Figure 5(v)

Date: September 15, 1976

BCHPA 1575 #102919 & #102920

NOTE:

- **Widespread valley bottom vevegetation.**
- **Vegetation colonization on higher elevation gravel bars.**
- **Bank erosion at F and N.**
- **Further gravel bar movement and possible increased sediment deposition at M.**

Discharge:

Gold River Below Ucona River	**37.7 m^3/s**

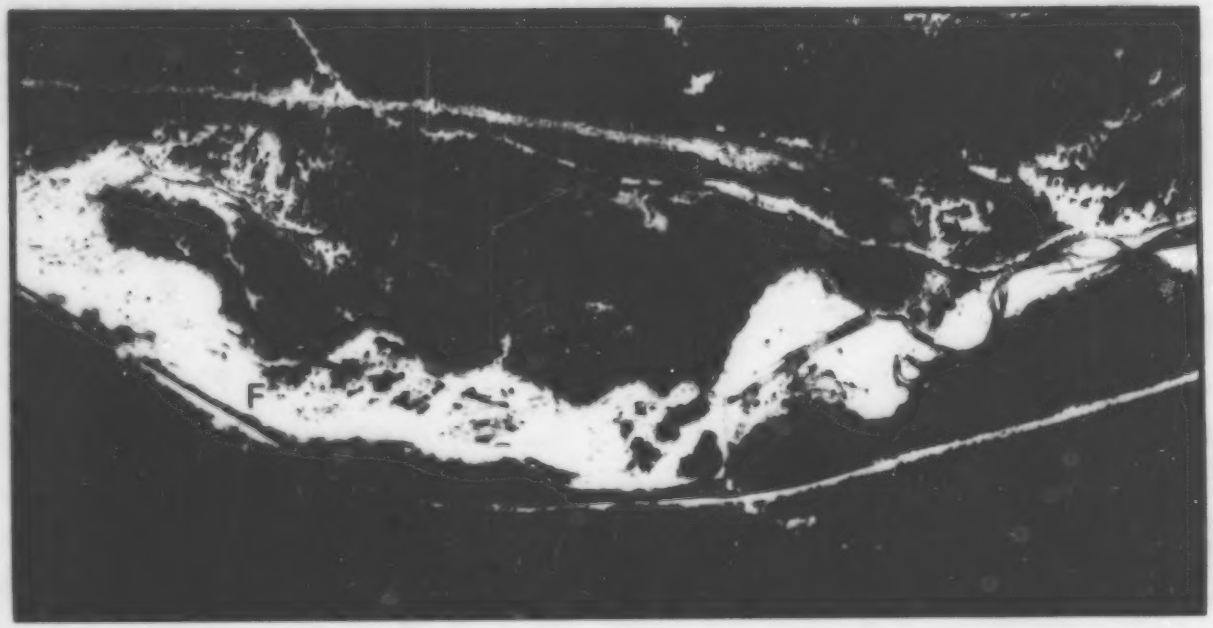

Figure 5(vi)

Date: September 22, 1987

SRS3602 #169 & #168

NOTE:

- **Further maturation of valley flat vegetation and locally increased colonization of higher elevation gravel bars.**
- **Rip-rap replacement at F.**
- **Continued channel shifting and movement of gravel.**

Discharge:

Gold River Below Ucona River	**49.9 m^3/s**

Figure 5(vii)

SRS4977 #151, #150, #149 & #148

NOTE:

- Increased width of Transmission Line Right-of-Way at J.
- Extensive reworking of gravel bars and changes in channel location, possible increase in the volume of unvegetated sediment stored in this section of channel.

Discharge:

Elk River Above Campbell Lake	2.46 m^3/s
Heber River Near Gold River	9.22 m^3/s
Gold River Below Ucona River	61.3 m^3/s

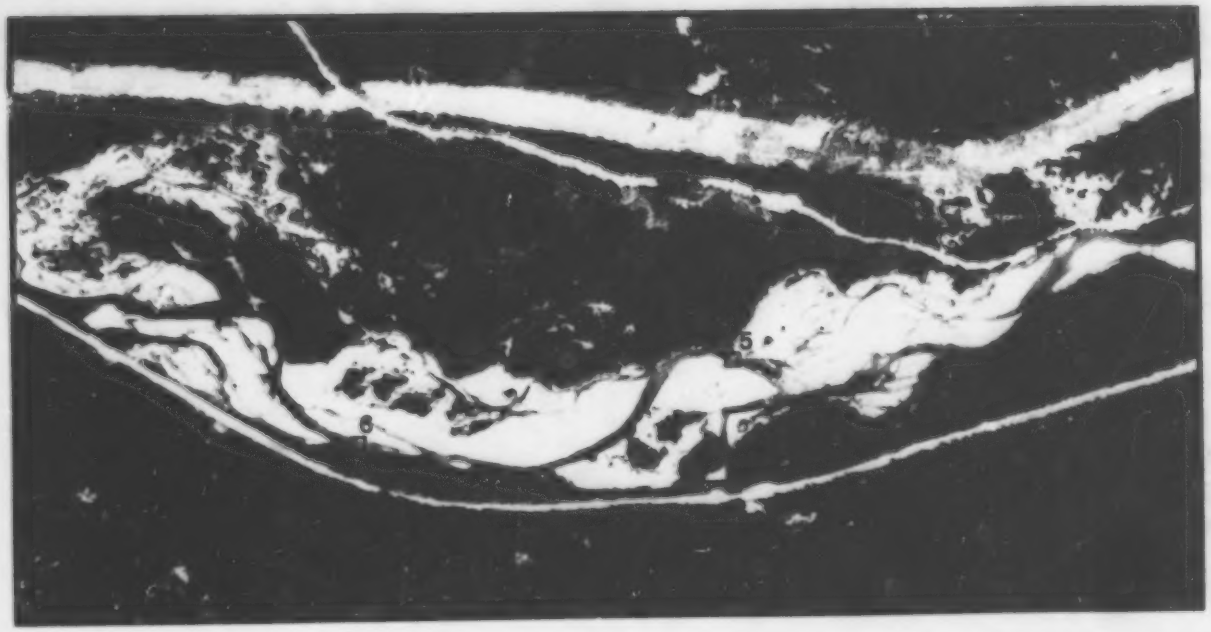

Figure 5(viii)

Date: June 20, 1995

30BCB95046 #110

NOTE:

- The unvegetated channel width is smaller than in 1996, but still much wider than in 1931.
- Continued presence of mobile gravel bars and a wide, laterally unstable river channel.

Discharge:

Elk River Above Campbell Lake	1.88 m^3/s
Heber River Near Gold River	17.1 m^3/s
Gold River Below Ucona River	48.1 m^3/s

☐ Kilometer Marks

Figure 5B: Historical changes in channel morphology on Elk River, B.C., Km 6 to 5 *(from M. Miles and Associates Ltd., 1999b).*

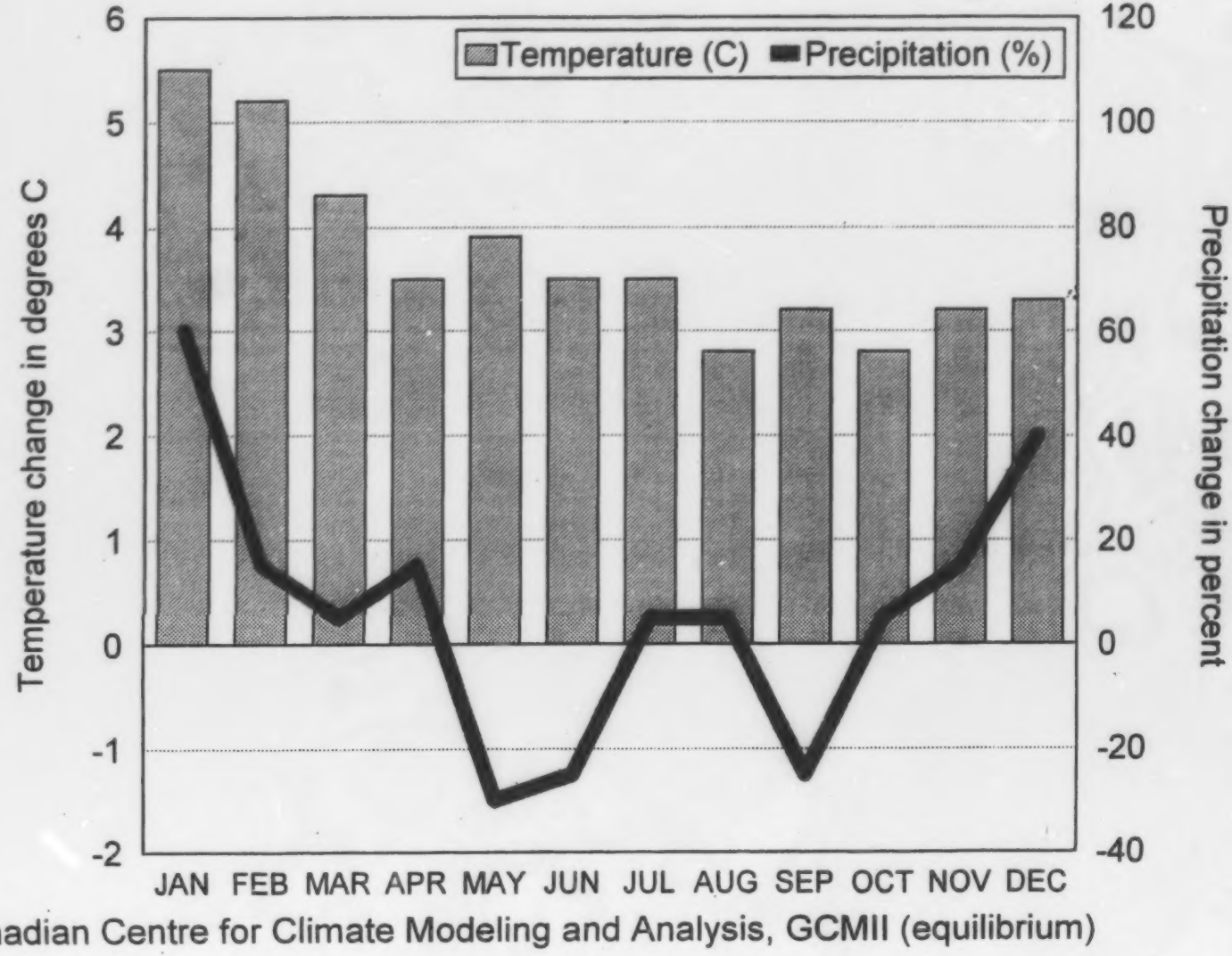

Figure 6: Projected climate changes in southwest B.C. due to doubling CO_2 concentrations *(from Eric Taylor, Pers. Comm.)*.

Looking downstream along the initially excavated channel.

Looking downstream showing gravel placement in a rip-rap and filter cloth lined channel.

Plate1: Construction of spawning channel at Logan Lake (B.C.) in 1991. (Photos courtesy of Brian Chan).

Looking upstream showing the completed channel. The water is supplied by a pump.

Spawning rainbow trout.

Plate 2: Completed spawning channel at Logan Lake (B.C.). (Photos courtesy of Brian Chan).

APPENDIX 1:
WATER QUALITY REQUIREMENTS FOR RAINBOW TROUT

A1.1 INTRODUCTION

Ideally, rainbow trout should have water with adequate oxygen, suitable pH level and safe, low, concentrations of ammonia, heavy metals and sediment. It is not within the scope of this report to discuss in detail the complex relationships among ammonia levels, oxygen concentration, pH and heavy metal toxicity. Therefore, we will review oxygen, pH and temperature requirements and provide information on the limits for ammonia, heavy metals and suspended sediment.

A1.2 OXYGEN REQUIREMENTS

There is no single level of oxygen requirement for rainbow trout. A fish's oxygen demand rises with temperature while the solubility of oxygen decreases with an increase in temperature. The solubility of oxygen is 14.62, 11.29, 9.09 and 7.56 mg/L at 0, 10, 20 and 30°C, respectively *(Cole, 1983)*. Oxygen levels for trout should, ideally, be near saturation. There may be some subjectivity in this approach, however, *Davis (1975)* expressed the "belief" that we should look for the "no-effect" level. Fish may survive at lower oxygen concentrations but critical activities become impaired at these levels.

The concentration of one environmental element may influence the toxicity of another. For example, low oxygen levels may increase the toxicity of ammonia. In a study of the influence of oxygen concentration on ammonia toxicity, *Thurston et al. (1981)* showed that there was a positive linear relationship between the LC_{50} of un-ionized ammonia and dissolved oxygen. [1] *Thurston et al. (1981)* cite eleven references that support their findings. The 96 hr LC_{50} was 0.4 mg NH_3/L at 3.0 parts per million (ppm) of oxygen and 0.7 mg NH_3/L at 9.0 ppm oxygen. Requirements for oxygen levels should take into account possible bursts of ammonia in the environment where such human impacts are possible.

Davis (1975) provided an excellent review of the minimum oxygen requirements for aquatic life. *Table A1.1* summarizes some of this information for rainbow trout.

Oxygen requirements for eggs in the intra-gravel environment increase with the age of the embryo in the egg. No survival occurred in redds where mean dissolved oxygen concentration was below 4.3 mg/L. Survival increased sharply above oxygen concentrations of 5 mg/L *(Sowden and Power, 1985)*. Oxygen requirements for trout eggs must take into consideration the rate of water movement through the gravel and the needs of the most sensitive stage of egg development.

A1.3 pH

Rainbow trout have a low tolerance to reduced pH. The low end of the tolerance range reported in *Ford et al., (1995)* was pH 5.5 to 6.0. Levels of pH from 6 to 9 are harmless to fish under most circumstances and those above 9 are likely to be harmful *(Table A1.2)*. Extremely low pH levels cause coagulation of gill mucus and reduces the capacity of blood to carry oxygen. Low pH may have the synergistic effect of increasing the toxicity of heavy metals.

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1 LC_{50} is defined as the concentration of a particular material that kills 50% of the test animals within a specified period. The period is usually 96 hrs, hence 96 hr LC_{50}.

A1.4 AMMONIA TOLERANCE

The concentration of total ammonia, NH_3 + NH_4, should not exceed 2.0 mg/L. However, the recommended concentration limits for total ammonia vary with both pH and water temperature *(Anonymous, 1995c)*.

The effects of pH, temperature and ammonia are inter-dependent. Guidelines for total ammonia permit as much as 2.5 mg/L at 0.0°C and a pH of 6.5 and as little as 0.08 mg/L at 30°C and a pH of 9.0 *(Table A1.3* from *Anonymous, 1995c)*.

A1.5 HEAVY METAL TOLERANCE

Acceptable concentrations of heavy metals in soft water range from 0.05 mg/L for zinc to 25 mg/L for nickel *(Anonymous, 1995c)*. However, oxygen concentration, pH and water hardness influence the toxicity of heavy metals. Increases in the hardness of water, as measured in mg/L $CaCO_3$, increases the acceptable concentration of heavy metals. (*Table A1.4* - information from *Anonymous, 1995c*).

The toxicity of some of the metals in *Table A1.4* may be additive. The toxicities of zinc, lead and copper to rainbow trout were markedly higher when oxygen saturation was <65%. Part of this effect may be caused because the trout had to move more metal-bearing water over their gills at the lower oxygen saturation levels *(Davis, 1975)*.

A1.6 IRON TOLERANCE

Species of fish show variable sensitivity to iron. Iron hydroxide precipitate interferes with gill function through occlusion of the gill lamellae *(Anonymous, 1995c)*. The recommended concentration for iron is below 0.3 mg/L.

A1.7 SUSPENDED SOLIDS TOLERANCE

Exposure to high concentrations of suspended solids is not unusual for populations of rainbow trout. Concentrations of several thousand mg/L of suspended sediment may not be lethal to trout during exposures of several hours or days *(Anonymous, 1995c)*. However, high concentrations may have serious sub-lethal effects on the fish involved. These effects may range from damage to gill tissue to alteration of behaviour and distribution. Lower levels of suspended solids may cause stress to trout and impact behaviour and other organisms in the environment. *Newcombe and Jensen (1996)* developed equations that quantified the responses of fish to varying durations of exposure and concentration.

High turbidity or concentration of suspended sediments have been reported to cause such effects as reduced survival, growth, food conversion and feeding, altered food selection and behaviour. They increase disease risk, cortisol and hematocrit levels and susceptibility to pathogens in rainbow trout *(Lloyd, 1987)*. Reduced primary production, abundance of fish food organisms and fish production have also been reported. Data in *Tables A1.5 and A1.6* are given to emphasize that water quality requirements must be much more sensitive than any standards which are based on lethality tests or experiments in very artificial situations.

Suspended solids from anthropogenic sources are often measured in situations where there is an existing background level of material. In these situations *Anonymous (1995c)* recommended that the additional material should not increase the Secchi disc reading by more than 10%. In Alaska, turbidity levels are not allowed to exceed natural levels by more than 25 JTU *(Lloyd 1987)*. In Yukon, the Yukon Placer Authorization allows suspended sediment discharges of ≤200 mg/L [2] or 0.2 to 1.0 ml/L [3] above natural background levels as measured in the effluent flow immediately before it enters the natural stream *(Anonymous, 1993)*.

The presence and volume of suspended solids must be considered in the context of other processes in the ecosystem that may be associated with it. The impact of suspended sediment on fish is difficult to separate from other impacts that may be associated with the input of sediment *(Everest et al., 1987)*. The movement of suspended sediment may be coincident with changes in temperature and hydrology, solar radiation, bed-load movement and channel morphology, *(Everest et al., 1987)*. The transport of suspended sediment may also be concurrent with the deposition of fine material from suspension into the streambed, where it may affect fish eggs or stream invertebrates *(Hartman and Scrivener, 1990)*.

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2 This standard is based on suspended sediment concentration.

3 This standard is based on settleable solid values measured in an Imhoff cone.

ABLE A1.1: INCIPIENT OXYGEN RESPONSE THRESHOLDS FOR RAINBOW TROUT, GATHERED FROM THE LITERATURE.

TROUT SIZE	TEMPERATURE (°C)	PO_2-mm Hg	ml O_2/L	mg O_2/L	% SAT.	RESPONSE TO OXYGEN LEVEL	REFERENCE
682-1136 g	20	78	3.2	4.59	50	Below this level blood is not fully saturated with O_2	Irving et al. (1941)
120-250 g	8.5-15	80-100	3.63-5.14	5.18-7.34	50.7-63.7	Circulatory changes occur, including a slowing of heart	Randall and Smith (1967)
3.3 (+ or- 1.4) cm	17 (+ or- 5)	156.6	6.82	9.74	100	Any reduction in O_2 led to more rapid death in cyanide	Downing (1954)
20 months old	8-10	78.8-79.9	4.16-3.97	5.94-5.67	50	43% reduction in max. swimming speed	Jones (1971)
20 months old	21-23	77.8-77.6	3.15-3.04	4.5-4.34	50	30% reduction in max. swimming speed	Jones (1971)
235-510 g	2.3-13	100	6.11-4.71	8.73-6.74	63.1-63.6	Blood is not fully saturated with oxygen below this level	Itazawa (1970)
-	15	78.45	3.55	5.08	50	Altered respiratory quotient, little capacity for anaerobic metabolism below this level	Kutty (1968)
-	15	80-100	3.63-5.43	5.18-6.47	51.0-63.7	Changes in oxygen transfer factor and effectiveness of O_2 exchange occur	Randall et al. (1967)
400-600 g	13.5	80	3.74	5.35	51	Breathing amplitude and buccal pressure elevated	Hughs and Saunders (1970)
300 g	10, 15, 20	80	3.30-4.03	4.71-5.75	50.7-51.3	Below this level, blood is not fully saturated	Cameron (1971)
1-11 g	17.5	93.8	4.05	5.78	60	Toxicity of Zn, Pb, phenols increase markedly below this level	Lloyd (1961)

OTE: From a summary by *Davis (1975)*. Oxygen concentrations are given in mg/L and g/L for sake of comparison. Some sources used mg/l and others used g/l. The measure that was absent was calculated for the sake of uniformity.

ABLE A1.2: SUMMARY OF THE EFFECTS OF pH VALUES ON FISH

pH RANGE	EFFECT
3.0 - 3.5	Unlikely that any fish can survive for more than a few hours in this range, although some plants and invertebrates can be found at pH values lower than this.
3.5 - 4.0	This range is lethal to salmonids. There is evidence that roach, tench, perch and pike can survive in this range, presumably after a period of acclimation to slightly higher, non lethal levels, but the lower end of this range may still be lethal for roach.
4.0 - 4.5	Likely to be harmful to salmonids, tench, bream, roach, goldfish and common carp which have not previously been acclimated to low pH values, although the resistance to this pH range increases with the size and age of the fish. Fish can be acclimated to these levels but of perch, bream, roach and pike, only the last named may be able to breed.
4.5 - 5.0	Likely to be harmful to the eggs and fry of salmonids and to adults particularly in soft water containing low concentrations of calcium, sodium and chloride. Can be harmful to common carp.
5.0 - 6.0	Unlikely to be harmful to any species unless either the concentration of free carbon dioxide is greater than 20 mg/L or the water contains iron salts which are freshly precipitated as ferric hydroxide, the precise toxicity of which is not known. The lower end of this range may be harmful to nonacclimated salmonids if the calcium, sodium and chloride concentrations or the temperature of the water are low, and may be detrimental to roach production.
6.0 - 6.5	Unlikely to be harmful to fish unless free carbon dioxide is present in excess of 100 mg/L.
6.5 - 9.0	Harmless to fish, although the toxicity of other poisons may be affected by changes within this range.
9.0 - 9.5	Likely to be harmful to salmonids and perch if present for a considerable length of time.
9.5 - 10.0	Lethal to salmonids over a prolonged period of time but can be withstood for short periods. May be harmful to developmental stages of some species.
10.0 - 10.5	Can be withstood by roach and salmonids for short periods but lethal over a prolonged period.
10.5 - 11.0	Rapidly lethal to salmonids. Prolonged exposure to the upper limit of this range is lethal to carp, tench, goldfish and pike.
11.0 - 11.5	Rapidly lethal to all species of fish.

NOTE: From *Anonymous, 1995*c - [Source: *Alabaster and Lloyd, 1982*].

ABLE A1.3: RECOMMENDED GUIDELINES FOR TOTAL AMMONIA (NH_3)

pH	AMMONIA CONCENTRATION (mg/L) AT FOLLOWING TEMPERATURES (°C)						
	0.00	5.00	10.00	15.00	20.00	25.00	30.00
6.50	2.5	2.4	2.2	2.2	1.49	1.04	0.73
6.75	2.5	2.4	2.2	2.2	1.49	1.04	0.73
7.00	2.5	2.4	2.2	2.2	1.49	1.04	0.74
7.25	2.5	2.4	2.2	2.2	1.50	1.04	0.74
7.50	2.5	2.4	2.2	2.2	1.50	1.05	0.74
7.75	2.3	2.2	2.1	2.0	1.40	0.99	0.71
8.00	1.53	1.44	1.37	1.33	0.93	0.66	0.47
8.25	0.87	0.82	0.78	0.76	0.54	0.39	0.28
8.50	0.49	0.47	0.45	0.44	0.32	0.23	0.17
8.75	0.28	0.27	0.26	0.27	0.19	0.16	0.11
9.00	0.16	0.16	0.16	0.16	0.13	0.10	0.08

OTE: From *Anonymous, 1995c-* [Source: *U.S. EPA, 1985*].

TABLE A1.4: GUIDELINES FOR ACCEPTABLE CONCENTRATIONS OF HEAVY METALS AT WATER HARDNESS LEVELS OF 0.0 TO 300 µg/L CaCO3
(Adapted From Anonymous, 1995c).

METAL	TOTAL HARDNESS $CaCO_3$	METAL CONCENTRATION µg/L
Cu	0 - 60	2.0
	60 - 120	2.0
	120 - 180	4.0
	>180	6.0
Pb	0 - 60	1.0
	60 - 120	2.0
	120 - 180	4.0
	>180	7.0
Ni	0 - 60	25.0
	60 - 120	65.0
	120 - 180	110.0
	>180	150.0
Zn	0 - 60	1.05
	60 - 120	0.10
	120 - 180	0.20
	>180	0.30

TABLE A1.5: GUIDELINES FOR SUSPENDED SOLIDS (*From Anonymous, 1995c*).

MAXIMUM CONCENTRATION mg/L in the environment	TYPE OF FISHERIES	LEVEL OF PROTECTION
<25	No harmful effects	High
25 – 80	Good or moderate fisheries	Moderate
80 - 400	Good fisheries unlikely	Low
>400	Poor fisheries at best	Very Low

TABLE A1.6: SOME EFFECTS OF SUSPENDED SEDIMENT OR TURBIDITY ON RAINBOW TROUT.

EFFECT	LIFE STAGE	LOCATION	TURBIDITY	mg/L
Reduced Survival	Eggs	Great Britain	-	110
Reduced Survival	Eggs	Oregon	-	1,000 - 2,500
Reduced Survival	Juveniles	Great Britain	-	270
Reduced Survival	Juveniles	Oregon	-	1,000 - 2,500
Reduced Survival	Juveniles	Great Britain	-	90
Reduced Growth	Juveniles	Great Britain	-	50
Reduced Food Conv. Efficiency	Juveniles	Arizona	70 JTU	-
Reduced Feeding	Juveniles	Arizona	70 JTU	-
Reduced Conditioning Factor	Juveniles	Great Britain	-	110
Altered Diet	Juveniles	Great Britain	-	110
Stress	Juveniles	Oregon	-	2,000
Disease	Juveniles	Great Britain	-	270
Disease	Juveniles	Great Britain	-	100 - 200

NOTE: These data are from *Lloyd (1987)*. The original table in *Lloyd (1987)* provides the original authors for reported results. Turbidity, in nephelometric turbidity units (NTU), was correlated with concentration in mg/L in Alaskan waters. However, the relationship varied in different types of stream from a ratio of about one ppm:one NTU to 4ppm:one NTU. The ratio of NTU to JTU is about1:1 in *Lloyd, 1987*.

APPENDIX 2:
SYNOPSIS OF RESOURCE INVENTORY COMMITTEE PROCEDURES FOR LAKE INVENTORY

A2.1 INTRODUCTION

The Resource Inventory Committee Standards For Lake Inventory are briefly reviewed in this section. Comments have been prepared to indicate whether this information is adequate to predict the risk of winterkill or assess the effects of raising lake levels to provide additional fisheries habitat.

A2.2 SCOPE OF LAKE INVENTORY PROCEDURES

Chapter 3, Lake Inventory Standards And Procedures in *Ministry of Fisheries (1998a)* provides detailed direction about pre-field planning, data compilation and reporting requirements for a lake inventory. A flow chart is presented, such that inventory work on different lakes may be done in a consistent manner. The following ten tasks provide the foundation of a full lake inventory:

i) Describe terrain characteristics, lake setting, lake genesis, aspect, hillslope coupling and land use;

ii) Describe shoreline characteristics, i.e. type, cover and recreational facilities present;

iii) Describe and categorize lake access;

iv) Describe inlet and outlet streams, including full stream survey requirements as outlined in the survey project plan;

v) Describe fish communities, including fish species presence and relative abundance;

vi) Provide water quality information by field measurements and water sample analysis;

vii) Complete bathymetric survey to determine mean and maximum depth, lake volume and distribution of littoral areas;

viii) Record the presence and distribution of dominant aquatic flora;

ix) Observe and record aquatic wildlife; and

x) Photo-document physical and biological features of the lake.

Lake inventories may be done at a primary, more detailed, or a secondary level. The choice between these depends upon the reason for the inventory.

The following critical information on lake properties is required:

i) The magnitude of the lake based on drainage network, i.e. the number of first order streams contributing to the drainage area;

ii) The surface area of the lake;

iii) The lake elevation; and

iv) The biogeoclimatic zone.

. The procedure document outlines the field inventory organization in a multi-step sequence of activities:

i) Terrain characteristics are determined by lake setting, basin genesis, lake aspect, hillslope coupling and land use. The classifications of lake setting, basin genesis and land use provide a basis for prediction of productivity and winter-kill risk;

ii) Shoreline characteristics such as type, cover and land use must be described in the inventory. Shoreline type may be classified as a sand or gravel beach, or a wetland or vegetated shore. The contours of the shore terrain and distance inland that such contours extend must be determined to predict the amount of new shoal area that would be provided by raising the level of the lake. The inventory does not call for adequate information in this regard;

iii) The inlet and outlet streams must be listed and described. In primary lake surveys, information must be obtained on the first reach of each tributary and extend 500 m beyond this first reach. This information will indicate how raising the lake level has affected spawning and rearing habitat;

iv) The procedure calls for survey information that indicates personnel and agencies involved in the survey;

v) Access information, such as the method of reaching the lake and closest community, gives some indication of the quality of experience that may be sought by people using it. This information may indicate what the public would expect if the lake habitat had to be replaced;

vi) The bathymetric survey is an important part of the lake inventory. This survey establishes a benchmark and provides the maximum and mean depth of the lake, maximum water level, percent of littoral area (below 6 m) and lake volume. The relationship between littoral zone and deep water areas assists in providing an indication of productivity and the risk of winter-kill. The inventory does not, apparently, provide a measure of the area of bottom covered in sediment or the type of sediment. This information would provide clues regarding the risk of winterkill;

vii) The inventory requires that wildlife, such as beavers, that may affect fish habitat be listed. It also requires that reptiles, amphibians and mammals that are listed as being threatened or endangered by the Conservation Data Centre be recorded;

viii) The dominant emergent and submergent aquatic plants and the approximate area of the lake covered by them must be recorded. This information is important in two regards. First, it indicates lake productivity and secondly, if considered with other information, it indicates the risk of winterkill. The amount of vegetation may be indicative of fish productivity, however, such information must be considered in connection with the species composition of fish populations. Dense populations of non-sport fish may not contribute to the recreational value of the lake;

ix) The inventory procedure calls for photodocumentation of the area surrounding the lake, shoreline and riparian conditions, inlet and outlet streams, diseased, unidentified and representative fish from the catch, aquatic plant communities and other "relevant" features;

x) Water quality sampling is included in the inventory. Measured parameters include: Secchi disc depth, water colour, pH and conductivity at the surface and bottom, dissolved oxygen and temperature profiles and hydrogen sulfide detection or measurement. In primary lake surveys, water samples are to be taken and analysed in an approved laboratory for acidity, pH, alkalinity, nitrogen total and nitrogen as ammonia, nitrate and nitrite, total phosphorous and dissolved phosphorous, and filterable residue (TDS). Information on conductivity and phosphorous content, in combination with data on mean depth provides a measure of fish productivity *(Ryder, 1965)*; and

xi) The fish survey, for the primary lake inventory, provides information on species composition and relative abundance of species. The survey methods lay out the requirements for types of gear, numbers and locations of sets, and data recording. The methodology is intended to ensure that all categories of area are sampled with the appropriate gear. The sampling data sheets are specified and twelve types of required data are listed.

APPENDIX 3:
REVIEW OF TECHNIQUES FOR TRANSPORTING RAINBOW TROUT

A3.1 INTRODUCTION

In a typical transport operation rainbow trout are subject to stress during capture and handling and from the conditions of transport. They may also experience stress if the receiving environment is not appropriate. If the stress is severe, it will affect subsequent growth and survival. The following section will touch briefly on the history of handling and transport, outline the nature of the physiological processes that underlie the stress caused by handling and transport and describe methods for mitigating this stress. *Wedemeyer (1996)* defined stress as *"a physical, chemical or biological challenge that requires a compensatory physiological response by the fish"*.

A3.2 HISTORY OF HANDING AND TRANSPORT

Methods of handling and transport were analysed and discussed thoroughly by *Pennell (1991)* and *Wedemeyer (1996)*.

Transportation of fish dates back to the first records of aquaculture in China and the Roman Empire. In 1874, the first fish were transported in the USA by rail and by 1880 some of the basic principles involved in handling fish were recognized *(Wedemeyer, 1996)*. By 1930, motor driven compressors, re-circulators and refrigeration were used in fish transport. Since 1960, more physiological information has been available and the causes of difficulties in moving fish are much better understood.

A3.3 PHYSIOLOGICAL PROCESSES OF STRESS

Physiological concepts form the basis of good fish handling and transport. However, people who are transporting fish are continually faced with the problem of 'trade-offs' between moving fish economically and keeping stress and its impacts to an acceptable minimum.

Many of the problems of fish handling, and the stress caused by it, are related to constraints regarding gas exchange. Water, the medium in which fish live, has oxygen solubilities which range from 14.62 to 7.63 ppm at 0°C and 30°C, respectively *(Welch, 1952)*. In comparison, the air that we breathe is about 20% oxygen. Therefore, compared to land-dwelling animals, fish must be very efficient at extracting oxygen from their environment. Gas exchange occurs through counter-current mechanisms in the gills where up to 80% extraction of oxygen from water may occur *(Wedemeyer, 1996)*. Stress caused by handling and transport impedes the exchange of gas and is very detrimental to fish.

The responses to stress begin within the endocrine system. Handling and transport may cause the fish to release adrenaline which sets a number of responses in motion. The adrenaline causes the gills to expand to permit an increased gas exchange. The adrenaline will also reduce blood clotting risk and increase hyperglycemia. If these effects become too pronounced they will cause water balance problems. The fish may lose electrolytes, experience more stress and, in extreme cases, die. If CO_2 levels in the water, and then in the fish blood, increase too much the pH of the blood is lowered and the oxygen transport capacity of the blood is reduced *(Wedemeyer, 1996)*. Strenuous activity and the subsequent increase in lactic acid in the blood of the fish will also reduce the capacity of blood haemoglobin to take up oxygen.

A3.4 METHODS TO MITIGATE TRANSPORT STRESS

There are many measures that may be taken, either in preparation for or during transport of fish, that will reduce stress and loss of fish. These will ensure that the delivered product is in better condition and will have a higher survival rate. *Pennell (1991)* identified four important ways to reduce stress and its consequent effects. If these alone were followed, they would ameliorate the severity of handling and transport problems:

i) handle fish without de-watering them;
ii) count the fish electronically or pre-count and vaccinate the fish at least two weeks before transport ;
iii) use tranquillisers; and
iv) cut off food 24 to 48 hours before transport.

Pennell (1991) recommended that dissolved oxygen levels during transportation be held at >70% saturation. *Wedemeyer (1996)* recommends 80% saturation which is enough to permit fish to maintain one half maximum swimming activity. Some hatchery operations saturate the water that the fish are in for about 10 minutes immediately before transport. This super-saturation may be desirable but may also have negative effects. Oxygen concentrations at 200%, will cause a low rate of opercular movement. However, this high concentration will cause high CO_2 concentrations in the blood. Also, if fish are transported in water that is too heavily saturated, they may be stressed dangerously if the oxygen level in the receiving environment is relatively low.

The pH in the transport water should be held at about 7.8. The addition of calcium to the transport water will help maintain the pH at a desired level. Elevated concentrations of CO_2 decrease the pH of the water and increase the acidity of the blood in the fish. There is a positive and a negative aspect to this effect. Excretory products from the fish raise the concentration of ammonia in the water. Since the toxicity of ammonia is lower at low pH, the decreased pH is an advantage. However, long-term exposure to CO_2 concentrations above 15-20 mg/L leads to chronic stress *(Pennell, 1991)*. The rate of production of CO_2 is proportional to loading density, respiration rate, size, degree of activity, fed condition of the fish and light intensity *(Pennell, 1991)*. All these conditions can be managed by using proper techniques.

There are a number of drugs and handling methods that may be used to reduce excitement, swimming and overall metabolic rate. The concentrations of the drugs and the complications involved in their use are outlined in *Pennell (1991)* and *Wedemeyer (1996)*.

The benefits of using cold water during fish transport have been recognized for over 100 years. Hypothermia reduces the amounts of oxygen required and ammonia produced. *Wedemeyer (1996)* indicates that reducing water temperatures by 6°C and 8°C lowered oxygen consumption by rainbow trout by 20 and 50%, respectively. A reduction of 10°C reduces ammonia production by 50% *(Pennell, 1991)*. However, water in which fish are held or transported should not be cooled more than 10°C below ambient temperature. Although fish can tolerate a quick 10°C change of temperature, such a change can activate latent infections *(Wedemeyer, 1996)*.

Reduction of light intensity calms and lowers the activity and stress of fish during handling and transport.

Sea water, at 10 g/L or NaCl, at 3 to 10 g/L may be used to provide trout with osmotic relief and reduce stress. Concentrations should be kept below the isotonic level (i.e. an electrolyte concentration similar to that of tissue fluids). *Wedemeyer (1996)* discussed the use of polymers (POLYAQUA ®) to prevent scale loss and outbreak of the disease Saprolignia.

Provincial Government hatchery staff are very competent at both handling and transporting fish. However, there are no formal B.C. Hatchery manuals for transporting trout. Most hatcheries have worked out procedures which suit their specific needs.

Hauling tank design and operation are vital parts of fish transportation and transplanting. Hauling tanks vary in size, structure and degree of internal modification. *Wedemeyer (1996)* described tanks ranging from 500 to 150,000 gallons. Tanks may be constructed of aluminum, steel or fibreglass and most are insulated with 3 to 8 cm of polyurethane and are painted white to further reduce heating.

There are four primary requirements for hauling tank structure and operation:

i) re-circulating water at a desired rate;
ii) removal of CO_2;
iii) addition of air; and
iv) proper use of capacity.

In re-circulation at least 50% of the water must be exchanged per minute. Overhead spray bars may be used but this technique can cause water temperature increases of 1 to 3°C/hr and therefore refrigeration may be required. Some tanks are equipped with electrical aerators that re-circulate water through holes in the walls. These systems can increase water temperatures by 1°C in 4 to 5 hours *(Wedemeyer, 1996)*.

Removal of CO_2 from the head space over the water is accomplished by using an open tank or forced ventilation. It is important to use one of these measures in a closed tank because CO_2 concentrations may be increased by 30 mg/L in 90 min in a closed tank *(Wedemeyer, 1996)*.

Air must be added by use of devices such as pumps and carbon rod diffusers. Some haul units use aerators with oxygen injection which strips CO_2 and N_2 from the water. If pure oxygen is injected to 200% saturation there is risk of gas bubble disease and increased CO_2 levels in the blood. Some aeration may be produced by the use of splash baffles in the hauling tank, however, pumped re-circulation is more effective.

Correct loading density is dependant upon the size of the fish and the water temperature. The theoretical loading curves for juvenile salmonids are indicated on *Figure A3.1*. *Pennell (1991)* shows that loading density for fish may increase about 5-fold, at 5°C, with a fish size increase from 2 to 120 g. However, the relationships in *Figure A3.1* are approximations which will need to be modified according to variety of fish used, oxygen levels and type of tank.

Fish can be transported to remote locations by either a fixed-wing aircraft or a helicopter. Fish may be hauled by air in specially constructed tanks or in garbage bags held in containers. Ice and NaCl at 0.1% may be used in the bags. Fish loading under these conditions may range from 0.12 to 0.16 kg/L for a 45 -minute flight *(Wedemeyer, 1996)*. Fish may be also be hauled in helicopters in modified fire-fighting buckets, although air drops kill some of them. It costs $0.05 to $0.06 per smolt to haul steelhead outside of a helicopter in buckets that are supplied with air. It costs $0.03 to $0.04 per smolt to haul fish within the helicopter *(Wedemeyer, 1996)*. If fish are hauled in an aircraft, precautions must be taken to avoid gas-bubble disease. If the aircraft goes up as much as 625 m, this is equivalent to an increase in total gas pressure from 100 to 110% *(Wedemeyer, 1996)*.

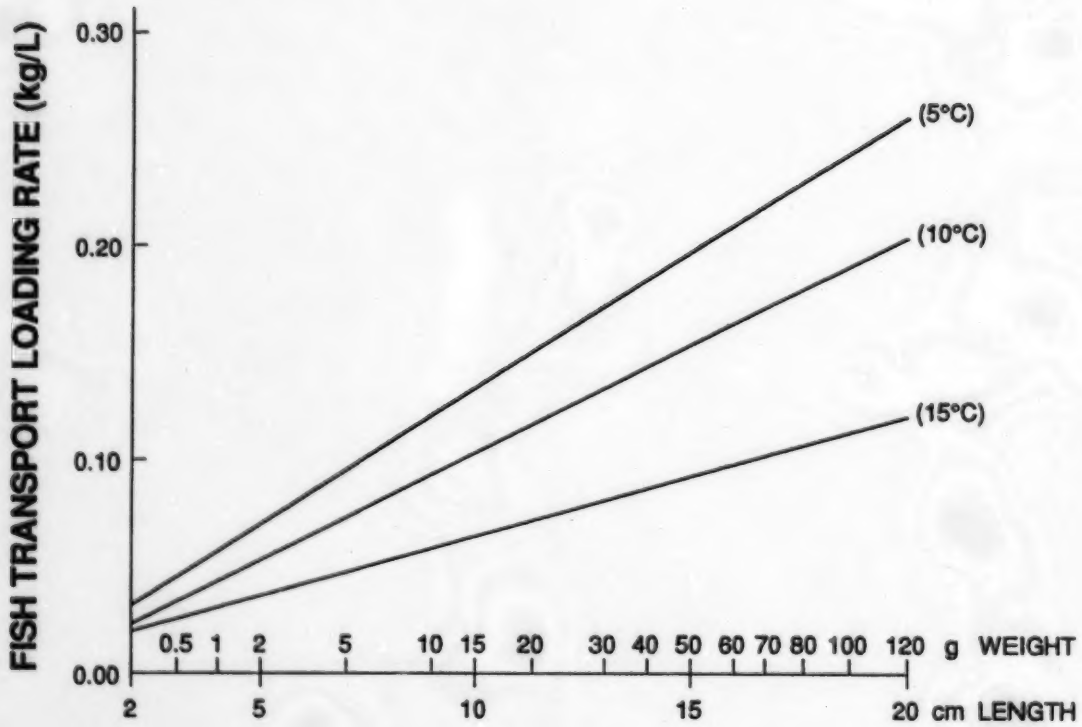


Figure A3.1: Safe theoretical loading curves for transport of juvenile salmonids *(from Pennell, 1991)*. Conditions may vary from one transportation situation to another. It is therefore recommended that procedures be tested before actual transport of a valuable load of fish.

APPENDIX 4:
TECHNIQUES TO MITIGATE THE EFFECTS OF WINTERKILL

A4.1 INTRODUCTION

Early methods for preventing winterkill included:

i) cutting holes in the ice;
ii) pumping water onto the ice;
iii) spraying water onto the ice;
iv) removing snow from the ice;
v) applying carbon or lampblack to the snow;
vi) manipulation of water levels; and
vii) augmentation with oxygenated water.

More recently, winterkill has been successfully prevented using a variety of aeration techniques. Historic and more modern practices are reviewed below.

A4.2 NON-AERATION TECHNIQUES

A4.2.1 Cutting Holes in the Ice

This is one of the oldest methods used *(Fast, 1994; Patriarche and Merna, 1970; Wirth, 1970)* and was proposed by *Greenbank (1945)*. This method fails because the oxygen diffuses very slowly down through the holes, the area of input is very small relative to lake area and the holes freeze and have to be re-opened. Virtually no oxygen is transferred relative to total lake demand and the technique is therefore unsuccessful.

A4.2.2 Pumping Water onto the Ice

Merna (1965) used 5, 7.5, 10 and 18 HP outboard motors to pump water over the ice on a small Michigan lake. The purpose was to wet the snow and darken it so that light penetration would permit photosynthesis. In the experiment the motors were mounted so that 'pumped' water could flow out across the ice to an arc of 6" holes located 200 ft from the motor. Within four hours, the holes were 20 by 50 ft in diameter and the motors had to be moved. Four motors flooded areas of 12,000 to 540,000 ft^2. Dissolved oxygen concentrations increased from 0.4 mg/L to >5.2 mg/L and from 0.3 mg/L to >3.4 mg/L at a depth of 36 inches *(Merna, 1965)*. The main drawback with this method was that the equipment had to be moved as the ice melted and the eroded ice created a safety hazard. Also, once the ice was melted for a certain distance, the water ran back into the lake through the hole and would not spread further. This method was not widely used.

A4.2.3 Spraying Water onto the Ice

Water was sprayed onto the snow/ice cover of a small lake in New York State using an irrigation spray system *(Flick, 1968)*. In this experiment water was sprayed onto the snow and allowed to run back into the lake through holes in the ice. A volume of 350 gal/min was sprayed out through a 200 ft long irrigation pipe. The snow was melted in two days and after 4 days the oxygen concentrations rose from 2 mg/L at all depths to 11, 9 and 2.5 mg/L at 1, 3 and 8 ft depth, respectively.

This method will work without the formation of large open areas in the ice. However, it has to be repeated if spraying is stopped because the area will freeze over and snow will cover it again.

A4.2.4 Removing Snow from the Ice

Snow removal can allow greater light penetration through the ice and into the water, thereby increasing photosynthetic activity *(Fast, 1994)*. The method is most effective when it is employed over submerged plant beds in shallow water. Snow removal should be done before dissolved oxygen problems start and must be repeated after each snowfall *(Flick, 1968)*. In a 178 ha lake in Wisconsin, 42 ha (20%) of the lake surface was cleared. Oxygen saturation was about 3 mg/L under the cleared area and <1.0 mg/L under the snow/ice covered area *(Fast, 1994)*.

Fast, (1994) had four comments on snow removal:

i) it is labour and equipment intensive and therefore expensive;

ii) it has to be repeated following each snowfall;

iii) it may not always be safe to send heavy equipment out onto the ice and the equipment may not be able to operate if the ice has water on it; and

iv) some lakes may not be accessible for snow removal equipment.

A4.2.5 Applying Carbon or Lampblack to the Snow

Fast (1994) reviewed two experiments *(Brynildson and Truog 1960; Hazzard 1968)* in which carbon or coal dust was applied to accelerate melting of snow and increase light penetration through the snow and ice. The treatment by *Brynildson and Truog (1960)* caused a "slight improvement in lake DO concentrations" *(Fast, 1994)*. However, the treatment was ineffectual if the weather was cloudy or if blowing snow covered the applied lampblack or carbon. Overall, the method was considered unsuccessful.

A4.2.6 Manipulation of Water Levels

These options involve raising water levels, dredging to deepen the water, or draw-down via a bottom drain to remove anoxic water.

The level of the water in Grebe Lake, Michigan was raised by closing the outlet. The lake had suffered winterkills "frequently" prior to the water level change. In this experiment a 6 to 12 inch change in water level prevented fish kills during the winter of 1963 *(Petriarche and Merna, 1970)*.

A very artificial method of deepening a lake involves drawing it down, compacting the bottom and re-filling. This technique is most applicable in shallow lakes where a moderate increase in depth can result in a sizeable increase in total volume *(e.g. Selbig, 1970)*. It is expensive and impractical on large lakes.

Another experiment involved the partial draw-down of an impoundment, using a bottom gate to remove the high oxygen demand hypolimnion water and allow the inflow of new water *(Wirth, 1970)*. The results of this work were inconclusive.

Measures such as dredging and drawing down lakes or compacting bottoms may have no application in natural British Columbia lakes. They are described here because they may be appropriate for use in projects where very artificial situations are created.

A4.2.7 Augmentation of Water Levels

Wirth (1970) described one example of a case in which the winter water supply to a lake was augmented by the addition of oxygen-saturated water from an upstream lake. The effectiveness of this approach was variable. It depended upon the quantity and quality of the water available and the severity of the winterkill problem *(Wirth, 1970)*.

A4.3 AERATION

A4.3.1 Introductory Comments

Aeration has been experimented with since 1945 and has now developed to the point where it is the most commonly used technique to prevent winterkill. The most frequently used systems are described below. We have also discussed the advantages and disadvantages of specific equipment and indicate the situations where various techniques have best application.

Aeration is intended to prevent winterkill by one or both of the following means:

i) water is carried upwards by the movement of rising gas bubbles. This water is warmer than that immediately under the ice and melts the ice to create an opening. The open water provides a greater surface area for oxygen absorption, greater light penetration and more photosynthetic activity; and

ii) oxygen is absorbed directly from the rising gas bubbles.

Systems for diffusing oxygen into the water and/or causing upwelling include:

i) line-release circulator;
ii) point-release circulator;
iii) helixor aeration and mixing system;
iv) submerged hypolimnion aerator;
v) Bernhardt full-lift hypolimnetic aerator;
vi) pump and baffle aerators;
vii) Quintero and Garton axial-flow re-circulation pump;
viii) surface aspirating pumps;
ix) molecular oxygen injection;
x) side stream pumping of liquid oxygen; and
xi) surface aeration.

A4.3.2 Line-release Circulator

Rasmussen (1960) used an 1,100 ft piece of ¾ inch pipe in a loop to aerate a 40 ft deep lake (Soda Lake) in Wyoming. The pipe was perforated with 1/32 inch holes every 20 ft. The loop was attached to the compressor with a 15 ft metal pipe to avoid heat damage to the plastic pipe. Pumping from

November 17 to 22 opened a hole in 6 inch ice and raised oxygen levels up to 100 yards from the pipe. The procedure was considered successful.

Halsey (1968) re-circulated Corbett Lake, B.C. just prior to ice formation and prevented winterkill of rainbow trout and brook trout. The aeration system used was an Atlas Copco VT 4, 4.5 m^3/min compressor. The 726 m diffuser loop was formed from a 2.5 cm inside diameter plastic pipe with 0.8 mm perforations every 3.7 m. An attempt was made to suspend the pipe 12 to 13 m below the surface. About 80% of the pipe lay on the bottom and did not function from the depth desired.

A4.3.3 Point-release Circulator

A point-release circulator was installed at Corbett Lake, B.C. *(Halsey and Galbraith, 1971)* and, replaced the line-release circulator used for two prior years *(Halsey, 1968)*. The point-release circulator was powered by an Atlas Copco KP6, 35 cf/m compressor. The point-release diffuser was constructed in the form of a 60 cm cross with 3.8 cm metal arms, perforated with 0.8 mm holes. The diffuser was suspended from a raft, air was supplied via a pipe to the raft and then down to the suspended diffuser *(Halsey and Galbraith, 1971)*. The diffuser was tested in three different configurations at a depth of 15.25 m:

i) located at the lower end of a 12.8 x 0.6 m pipe;

ii) in the same depth location but at the lower end of a pipe, 2 m long x 0.6 m in diameter; and

iii) in the same location with no pipe above it.

The increase in the amount of oxygen was highest when the point-release circulator was operated without any pipe above it. In the autumn of 1964, the point-release system provided *"a higher total oxygen content"* than the line-release system. However, with the line-release system *"the increase was greater"*.

The total construction cost for the point-release system was $774, exclusive of labour and design. The monthly operation cost was $135 *(Halsey and Galbraith, 1971)*.

Three point-release diffusers and one compressor were used in Yellow Lake, B.C. to increase oxygen saturation *(Halsey and MacDonald, 1971)*. Initially, the diffusers were set at a depth of 15 m. Operation of the system reduced the oxygen level in the epilimnion because it brought H_2S to the top. When the diffusers were raised and operated at 3 m, the oxygen level was increased.

The operating cost for the experiment was $1,800. This included fuel, compressor rental, pipe, fittings and freight.

A4.3.4 Helixor Aeration and Mixing System

Helixor aeration systems have been widely used *(Bandow, 1986; Fast, 1994; Johnson and Skrypek, 1975; Lackey and Holmes, 1972; Wirth, 1970)*. Helixor aerators normally consist of a 47.5 cm diameter plastic pipe with a helical dividing partition along its full length *(Wirth, 1970)*. The pipe is suspended vertically from near the surface to near the mud-water interface *(Fast, 1994)*. Air is delivered, from shore-based compressors, via a 3.8 cm diameter plastic pipe. A variety of different compressors or blowers have been used to power Helixor aerators in the USA *(Wirth, 1970)*.

The advantage of the Helixor aerator is that the air has a longer period to mix with the water as it moves up the helical spiral in the pipe. The turbulent flow within the pipe emerges in a "surface boil" as the water spills outward from the top of the pipe *(Wirth, 1970)*. Helixor aerators have been used in groups to provide greater aeration capacity and area *(Bandow, 1986; Johnson and Skrypek, 1975)*. Eleven helixor units operating from November 20 to March 20, in Shetek Lake, Minnesota produced an opening of about 25 ha and raised oxygen concentration to 8 mg/L *(Johnson and Skrypek, 1975)*.

Helixor aerators in Lura and Elysian Lakes, Minnesota, stabilized oxygen concentrations at low but safe levels for the fish present. Oxygen concentrations decreased at the outset of aeration. This may have resulted from an initial increase in oxygen consumption by lake bottom or suspended sediments *(Bandow, 1986)*. At the end of the period of aeration, oxygen concentrations at locations furthest from the aerators were the lowest measured. In Lura Lake, the aerators created a larger opening than they did in Elysian Lake. Lura Lake was deeper and had a larger volume of warm water available for ice melting *(Bandow, 1986)*.

The system has advantages and disadvantages. It usually lifts water from the lowest part of the lake where oxygen concentrations are lowest and oxygen uptake is consequently the most efficient. Helixor systems can also inject air at a substantial depth where high hydrostatic pressure enhances oxygen uptake *(Bandow, 1986)*. Helixor aerators can be effective for oxygen supplementation and ice removal. However, they cannot be used for aeration or circulation of hypolimnion water without disturbance of the epilimnion. This system of aeration carries risks to people involved in recreational activities on the ice and air lines must be protected from freezing during intervals when there is no pumping.

A4.3.5 Submerged Hypolimnion Aerator

Use of hypolimnetic aerators is described in *Fast (1994); Fast et al. (1975); Garrell et al. (1977)* and *Soltero et al. (1994)*. This type of aeration system is placed just below the thermocline or lower epilimnion. The air that is pumped through it lifts the water/air mixture to the level of the top of the aerator and forces it back down to an exit level at the bottom of the aerator *(Figure A4.1)*. The air that lifts the water/air mixture to the top of the aerator is then vented off via a pipe that projects above the lake surface. The venting system prevents bubbles from the aerator disturbing or mixing the epilimnion.

Hypolimnetic aerators have been effective in some situations, but have presented problems in others. This equipment has no moving parts under the water and as a consequence it is usually trouble-free. They were effective in increasing the amount of dissolved oxygen under ice in two Wisconsin lakes *(Smith et al., 1975*, cited in *Fast, 1994)*. Hypolimnetic aeration, using a 'Limno' aerator, in Lake Waccabuc, New York, increased oxygen concentrations to 4 mg/L compared to 0.0 mg/L in the same time and depth strata the year before *(Fast et al., 1975)*. Oxygen profiles *(included as 5, Fast et al., 1975)* illustrate that a zone of anoxic water persisted for over two months after aeration.

A somewhat different type of submerged hypolimnion aerator was used by *Fast (1973b)* to create suitable habitat conditions for rainbow trout below the thermocline in a small Michigan lake. As illustrated on *Figure A4.2*, this system consists of a 1.8 m diameter pipe which extends from 3 m above the lake surface to 9.2 m below it. A second pipe, 1.4 m in diameter, extends from the lake surface to a depth of 15.5 m. As discussed in *Bernhardt (1967)* and cited in *Fast (1973b)*, it is capable of aerating the hypolimnion without disturbing the epilimnion.

Operation of the system from June 14 to September 7, 1970 raised the hypolimnion oxygen level from near 0.0 to 9.0 mg/L. Stratification of the lake was weakened but not eliminated. Trout, which had

formerly been restricted to a narrow zone between an unsuitably warm epilimnion and an anoxic hypolimnion, were able to occupy the whole hypolimnion *(Fast, 1973b)*.

Predictions have been made that hypolimnetic aeration would decrease phosphorus concentration and reduce NH_4-N by converting it to NO_3-N *(Garrell et al., 1977)*. Aeration of two small lakes in New York caused a small reduction in phosphorus but it produced no significant change in NH_3-N. The expected benefits of aeration were presumed to have been masked by heavy input of septic drainage *(Garrell et al., 1977)*.

There is a risk of nitrogen super-saturation with hypolimnetic aeration *(Fast et al., 1975)*. Injection of air at 14 m depth could lead to 200 % N_2 saturation. If fish, which were exposed to such conditions, migrated vertically they would be vulnerable to gas bubble trauma *(Fast et al., 1975)*. It is unclear whether or not such effects (and consequent mortality) arose in the lakes with which *Fast et al. (1975)* carried out their experiments.

Hypolimnetic aerators must be correctly anchored. A unit used in Medical Lake, WA, broke loose and was ineffective *(Soltero et al., 1994)*. If hypolimnetic aerators become frozen into the ice they will continue to operate. However, they may lose some effectiveness. An ice-bound aerator, in a Wisconsin lake, which could not adjust its buoyancy was only 40% as efficient as during open water conditions *(Fast, 1994)*.

A4.3.6 Bernhardt Full-Lift Hypolimnetic Aerator

This type of aerator was described in *Soltero et al., (1994)*. It consists of a riser tube, a separator chamber at the surface and exit tubes that are some distance from the intake of the riser tube. *Ashley (1985)*, cited in *Soltero et al. (1994)*, improved the original design of the full-lift aerator. A unit used in Medical Lake, WA had a 1.5 m diameter inflow (riser tube), a 6.4 m long, 3.5 m wide and 2.1 m deep separator chamber and an exit tube 1.5 m in diameter. This unit was effective in reducing total phosphorus and nitrogen concentrations and increasing dissolved oxygen and water temperature. Dissolved oxygen concentrations were raised by 9 mg/L during April, 1991 *(Soltero et al., 1994)*.

A4.3.7 Pump and Baffle Aerators

The pump and baffle aerator consists of a high volume pump, an inclined plane with steps or baffles and a pipe system connecting the two. *Fast (1994)* and *Bandow (1986)* described three different systems. In a pump and baffle unit the water is pumped to the top of an inclined plane containing 5 to 14 baffles *(Fast, 1994)*. Units described ranged from 1.2 to 2.4 m wide and 6.1 to 11 m long. The water cascades down the inclined plane and is aerated as it plunges over the baffles. The aerators can be mounted on trailers and powered by tractors or diesel motors. A unit described by *Fast (1994)* pumped >12,000 g/m and raised oxygen levels by 10 mg/L in one pass. A unit described by *Bandow (1986)* pumped 2,000 g/m and discharged water with an oxygen concentration of 8.6 mg/L.

Pump and baffle systems do not rely on open water for aeration and do not require a large volume of 'warm' water from under the ice. Cold, aerated water may be allowed to re-enter the lake just below the ice, but not mix all the way to the bottom. In this way the upper water may be oxygenated but oxygen saturated water is kept away from the bottom sediments which would consume oxygen rapidly *(Fast, 1994)*. Pump and baffle systems may be the "best choice" for extremely shallow lakes where heat storage is limited. However, cost effectiveness was not established for large lakes. Because of

the way pump and baffle aerators work (and because of cost effectiveness in large lakes) their value may be limited to small, shallow lakes.

A4.3.8 Quintero and Garton Axial-flow Re-circulation Pump

This type of re-circulation equipment was developed by *Quintero and Garton (1973)* and is described by *Summerfelt et al. (1980)* and *Summerfelt (1983)*. It consists of an axial flow pump which is placed just below the ice. The impellers in pumps used by *Summerfelt et al., (1980)* varied in diameter between 46 and 122 cm. The equipment lifts warmer water upward to melt the ice and create an open area of water in which oxygen diffusion may take place. The axial flow pump does not depend upon bubbles for aeration or for moving the water. The 122 cm diameter impeller moved 37,100 m^3/d. The 46 cm diameter impeller created a 19 m wide hole in the ice in 72 hours. The Quintereo and Garton axial flow pump was economical. In the up-flow mode it moved 2,412 m^3/h at an energy rate of 373 watts/h and was >4 times as efficient at moving water in comparison to bubble aeration systems *(Summerfelt et al., 1980)*.

Fall aeration was considered particularly effective. It increased total oxygen in the lake from 787 to 1,044 kg and increased the concentration of oxygen to 7.6 mg/L in the whole lake. Based on this experience, *Summerfelt et al. (1980)* and *Summerfelt (1983)* recommend aeration during the fall to increase stored oxygen and to decrease the amount of BOD within the water column and the sediments. Fall aeration also avoids the hazard created by large ice holes with open water during the winter.

A4.3.9 Surface Aspirating Pumps

Bandow (1986) described an experiment using floating directional aspirators. These units consist of a hollow tube with a submerged propeller at the end of it. The submerged propeller draws air into the water at high velocity and creates turbulence at the outlet end. The description did not provide a clear picture of how this equipment was oriented and operated. There were difficulties in the operation of 2 out of 6 units employed in this trial.

A second experiment tested the effectiveness of using ceramic, micro-pore diffusers. These were powered from compressors on shore. Frequent difficulties were experienced as the equipment either broke down or worked at reduced capacity *(Bandow, 1986)*.

A4.3.10 Molecular Oxygen Injection

Fast (1994) cited an experiment in which molecular oxygen was injected into a lake in South Dakota. Oxygen was diffused into the lake through four 1.9 m graphite diffusers. Oxygen depletion occurred with or without the diffusers. Free CO_2 and H_2S increased to 60 and 6 mg/L respectively. The method was not considered effective.

A4.3.11 Side Stream Pumping of Liquid Oxygen

Injection of liquid oxygen increased dissolved oxygen levels in a 0.73 ha quarry lake in Ohio and permitted planted rainbow trout to survive below the thermocline *(Fast et al., 1975)*. In order to inject the oxygen, water was pumped up from below the thermocline, injected with liquid oxygen and pumped back into the hypolimnion. After 3 weeks of injection the oxygen concentration increased from

<0.5 mg/L to 3 mg/L. After about 58 days the oxygen level was approximately 8 mg/L *(Fast et al., 1975)*. When aeration devices are used the rising bubbles strip CO_2 and ammonia from the water. If liquid oxygen is injected, such removal of CO_2 and ammonia does not occur. However, in the experiment described by *Fast et al.*, (1975), CO_2 and ammonia did not accumulate to toxic levels. However, *Fast et al. (1975)* indicates that long-term injection of liquid oxygen in soft water lakes could lead to an accumulation of CO_2 and ammonia.

A4.3.12 Surface Aeration

There have been a variety of mechanical devices for surface aeration *(Fast, 1994)*. These units provide aeration by spraying water into the air rather than pumping air into the water. They draw water up from some depth and create a boil and spray effect *(Fast, 1994)*. Most of the surface spray aerators have low capacity (1.5 HP) and the intake and outlet are close together. The largest unit described by *Fast (1994)* was 5 HP. In Colorado a 0.5 and a 1.09 HP aerator, working together, maintained an opening in 56 cm of ice and 15 cm of snow. The units mixed the water in the lake but were inadequate to maintain dissolved oxygen levels *(Fast, 1994)*.

These units are of interest because they are similar to the types now used in most lakes in British Columbia. The aerators used in B.C. are mounted on floats. They raise the water 2 to 3 m and spray it into the air to create an opening in the ice. For a further description see APPENDIX 5, SECTION 5.2 and *Plates A5.2.1 to A5.2.4*.

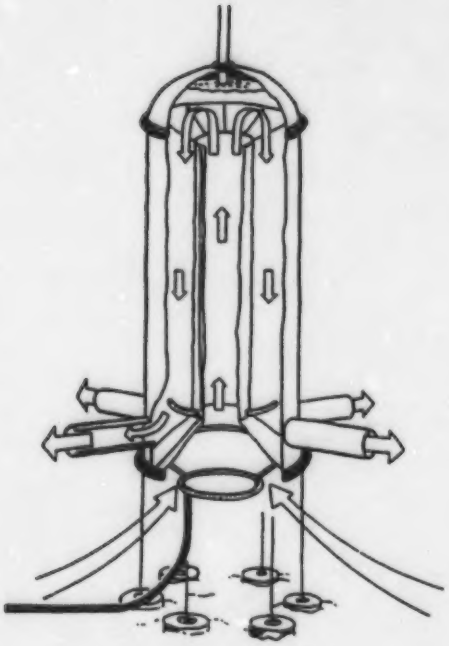


Figure A4.1: Schematic diagram of a flexible LIMNO™ hypolimnitic, partial lift aerator (*from Soltero et al., 1994*). Arrows indicate the direction of water flow into, through and out of the aerator. Air is vented through the pipe at the top of the aerator.

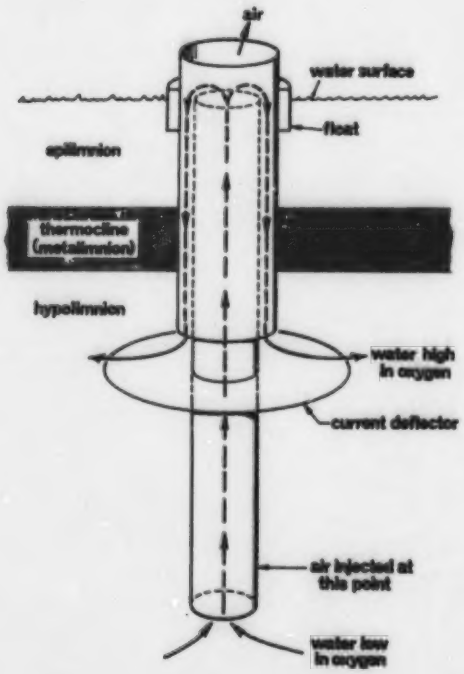


Figure A4.2: A submerged hypolimnitic aerator used in a small Michigan lake *(from Fast 1973b)*. Arrows indicate the path of water movement. Air is vented at the top of the aerator without disturbance to the epilimnion.

APPENDIX 5:
REVIEW OF AERATION PROJECTS UNDERTAKEN IN B.C.

A5.1 INTRODUCTION

Research on aeration techniques suitable for use in British Columbia was initiated by *Halsey (1968), Halsey and Galbraith (1971)* and *Halsey and MacDonald (1971)*. In 1979 a group of lakes were selected and aeration testing programs were started. *Ashley (1981)* described some of the results of these experiments and developed proposals for aeration of 12 additional lakes.

By 1984, at least 8 lakes were being aerated in B.C., all within Fish and Wildlife Branch Region 3 – Kamloops *(Sidney, 1984)*. Two of the 8 aerators were diesel-powered compressors and 6 were electrically powered. Operations were considered to be successful in preventing or reducing winterkill and increasing sport fishing options. Studies by *Ashley (1983, 1985), Ashley and Hall (1990)* and *Ashley et al. (1992)* added to the understanding and allowed the methodologies to be fine-tuned. This work provided guidance for the aeration schedules to be followed in 11 more lakes in the projects described in *Sidney (1984)*. Capital costs ranged from $8,000 to $18,000 per lake and maintenance costs were from $1,600 to $3,000/yr. The report by *Sidney (1984)* contains an Appendix by *K. Ashley, ("Lake Aeration Operation Strategies")*. This provides very useful guidance for aeration planning based on information on lake productivity, depth and turn-over characteristics.

Sidney (1991) completed a cost/benefit evaluation of aeration projects on 10 lakes, based on angler use from November 15, 1989, to February 4, 1990, in the Kamloops Region. The number of angler-hours ranged from 65 to 5,317 and the cost/benefit ratios for 7 of the lakes ranged from 0.4:1 to 18:1.

In our review, a number of active and inactive lake aeration projects were identified in the interior of B.C. A review of these projects was undertaken either by phone or by direct contact with MOELP fisheries staff during March and April 1999. The number of projects reviewed for each of the Fish and Wildlife Branch Regions is as follows:

Region 3 (Kamloops)	8
Region 4 (Kootenay)	0
Region 5 (Williams Lake)	4
Region 6 (Smithers)	0
Region 7 (Prince George and Fort St. John)	2
Region 8 (Penticton)	6
TOTAL	20

Brief descriptions of these projects are provided to show the different circumstances and problems associated with aeration operations within the MOELP Regions.

A5.2 REGION 3 (KAMLOOPS)

The eight surface aerators in the Kamloops region are effective, moderate in cost and operate trouble-free almost all of the time. The aerators are surface mounted units that sit on a float about 1 m x 1 m *(Plates A5.1 to A5.4)*. The impellers are 30 cm below the surface and draw water up from a depth of about 2 to 3 m. The units are powered through a waterproof electrical cable which is attached to a power source on shore. This type of unit has been adopted for use over most of the aeration sites in the province. Operation and maintenance costs on the units are low. Aerators that require 0.5 HP or

more are operated from a 220 v power supply. The smaller units, e.g. 1/3 HP, may be powered by a 110 v source. Installed cost of the aerator units is about $2,500 *(B. Chan, pers. comm)*. Duration of operation may vary from lake to lake, however, the seasonal cost for electricity is about $700. There is one major problem with the units. The aerators create holes up to 90 m in diameter. There are liability problems (Criminal Code of Canada, Section 273) associated with the creation of such holes in the ice *(B. Chan, pers. comm)*. Fencing and signs at prescribed intervals must be placed around the hole and checked regularly. Signs are required on all access points to the lake *(Plates A5.5 and A5.6)*. Fencing and signage costs are about $4,000 per unit *(B. Chan, pers. comm)*.

The choice of aeration equipment, the timing of operation and the trout stocking programs for the lakes involved have been worked out on the basis of more than a decade of experience. The projects in the Kamloops region are rated as very successful.

A5.3 REGION 4 (KOOTENAY)

There are no aerators in operation in Region 4 *(J. Hammond, pers. comm.)*. Four units were previously tried in the East Kootenay area. However, all projects were abandoned because of cost and maintenance problems.

A diesel powered unit with diffuser, as described in *Halsey and MacDonald (1971)*, was operated on Stoney Lake near the old Kimberley Airport. Breakdowns were frequent and the unit required regular maintenance. Major maintenance problems made it impractical to operate after about 1992 *(B. Westover, pers. comm.)*. Increase in rainfall during the last 7 to 8 years is reported to have raised the lake level by 3.5 m and no winterkills have occurred since then.

Johnson Lake, near Premier Lake, was aerated with an electric power source and a diffuser, as described in *Halsey and MacDonald (1971)*, but this operation was abandoned because the pH of the lake water was too high and fish survival was low *(B. Westover, pers. comm.)*. The aeration system worked well otherwise.

Campbell Lake, near Fort Steele, was aerated with a ¼ HP motor and a hydrovane re-circulator. This unit pulled water from the bottom and re-circulated it, but did not spray it into the air. The lake was located in a depression and the aerator created an inadequately sized opening so natural oxygen addition was insufficient.

A solar-powered aerator was tested in Wapiti Lake, near Wardner. The unit had no battery storage so it worked only while the sun shone. The unit therefore did not function effectively on cloudy days or at night. During snow periods the solar panels were covered and, if temperatures were low, the hole froze over *(B. Westover, pers. comm.)*.

A5.4 REGION 5 (WILLIAMS LAKE)

There are four surface aeration projects in Region 5 *(M. Lirette, pers. comm.)*. The aerators are similar to those used in Region 3 (Kamloops). Two units were installed on each lake. The capital and installation costs are about $15,000 per lake. Maintenance and electricity costs are about $1,500/year. The cost of buying and putting up the protective fences is $2,000 *(M. Lirette, pers. comm.)*. The period of operation is usually from January to late March.

Three operations have worked well and one is considered to be fair. The effectiveness of two of them may be jeopardized by the presence of Redside shiners (Richardsonius balteatus). Project success is evaluated on the basis of angler use of the lakes. Dewar, Irish, Higgins and Skulow Lakes support about 3,000 2,000, 1,000 and 500 angler days of use, respectively. Skulow Lake contains redside shiners as well as stocked rainbow and brook trout. Dewar Lake has recently been invaded by shiners, so rainbow trout stocking success is expected to decline in the future.

Trout populations in the aerated lakes are all maintained by stocking. The regional staff and hatchery operations people have developed a good understanding of stocking requirements in productive interior lakes. If natural recruitment occurs in addition to stocking, it may result in higher fish densities and lower growth rates and size. An example of this occurs in Higgins Lake where flow in the outlet creek provides spawning habitat and some fry recruitment. Fish in Higgins Lake are smaller than expected for the number of fish stocked annually.

Faunal changes have occurred in Dewar Lake with the advent of aeration and rainbow trout stocking *(M. Lirette, pers. comm.)*. Gammarid shrimps have declined in number and chironomids and mayflies have become more abundant.

There may be socio-economic consequences of aerating lakes and stocking rainbow trout. Property values around Dewar Lake rose when trout were successfully established. The government may be locked into continuing the aeration even if it became a lower priority for fisheries purposes. Concerns about liability apply to all aeration projects in Region 5.

A5.5 REGION 6 (SMITHERS)

There were no projects reported from this region.

A5.6 REGION 7 (PRINCE GEORGE AND FORT ST. JOHN)

There are lake-aeration projects on Inga and Sundance Lakes in MOELP Region 7, in the Fort St. John area. Both of these operations use surface aerators of the type used in the Kamloops region *(T. Euchner, pers. comm.)*. These lakes are both shallow, with maximum depths of 4 to 5 m, and contain large areas that are 2 m deep. The projects are successful and the aerators create openings up to 40 m across and maintain them even during periods of extreme cold.

There were initial developmental problems in aeration projects in the Fort St. John area. The first aerator (1984 to 1988) on Inga Lake was a wind-powered unit that consisted of an impeller in a long draw tube which was suspended in the water. This unit stopped and froze up when the wind stopped. It was not as functional as the present surface aerators.

A third aeration project was attempted in Beaver Lake, near Fort Nelson in 1985. A propane-powered, two cylinder engine was used to force air through a 10 cm pipe to within 2 m of the lake bottom to create a bubbling effect. The weather was extremely cold for long periods during the winter and there was a continuing maintenance problem. The land-based power unit never ran a full season and the project was abandoned in 1990 *(T. Euchner, pers. comm.)*. Beaver Lake is now stocked with 750 to 1,000 catchable sized rainbow trout that die during the winter if not taken by anglers.

A5.7 REGION 8 (PENTICTON)

There are six lake aeration projects in Region 8. Surface aerators of the type used in Regions 3 and 5 are used in four of the lakes and hydrovane units are used in two *(S. Matthews, pers. comm)*.

Projects in Yellow and Gardom Lakes employ hydrovane compressors *(Halsey and Galbraith, 1971)*. The diffusers are located above the hypolimnion to keep them from bringing up water with low oxygen concentration and circulating it in the epilimnion. To accomplish this, limnological conditions are monitored and diffuser levels are adjusted as required. The aerators are operated only in the late fall, from about the beginning of October to mid-November. The period and timing of operation varies depending upon the lake temperature.

Aeration permits rainbow trout and brook trout to exist year-around in Yellow Lake. However, yellow perch (Perca flavescens) and smallmouth bass (Micropterus dolomieui) also occur in the lake now *(S. Matthews, pers. comm.)*.

Surface aerators are used in four other lakes in Region 8 (Penticton). High elevation and complex basin shape may necessitate more than one aerator. Kidd Lake, about 5 km south of Aspen Grove, is an example of this. The elevation of Kidd Lake is about 990 m. It has a large littoral area and is very productive. Because of these conditions, three 1 HP aerators are used and the operation has been successful. Burnell Lake is a second example. It is also very productive and has two basins separated by shallow water. A 1 HP aerator has been used in each basin. Fish in one basin died when one of these aerators failed. Aside from this single mechanical failure, aeration of Burnell Lake has been very successful.

The surface aerators are operated during the winter period and start-up time varies from lake to lake. The unit on Lady King Lake is used longer. It operates from late September onward because the lake is not exposed to strong wind action and has low oxygen levels by late fall. The aerator on Burnell Lake is operated from mid-October until the ice goes out.

The unit cost of purchasing and installing aerators on Yellow and Gardom Lakes was between $10,000 and $12,000. The unit cost for electricity was about $300/month.

The cost for purchase and installation, excluding power line construction, was $2,500 per aerator in Kidd and Burnell Lakes. The total cost for purchase, installation and power supply to three aerators on Kidd Lake was about $15,000. Total costs for Burnell Lake were about $12,000. This high cost was due to the requirement for 600 m of powerline and poles.

The benefit/cost ratio on these projects is considered to be good. Kidd Lake supports 1,500 angler days of use. If angler days are valued at $35/day the revenue generated is over $52,000 *(S. Matthews, pers. comm.)*.

There was no electrical power to the aerators on Lady King Lake so the aerators were powered by a diesel generator which was less efficient. Because the diesel was run for a lodge it operated only 12 hr/d. Two aerators were required because of the 12 hr operation. Diesel fuel costs were approximately $2,500/season of operation *(S. Matthews, pers. comm.)*.

All six aeration projects in Region 8 (Penticton) are rated as successful.

Plate A5.1: The float upon which the surface aerator is mounted (copy of photo courtesy of B.Chan).

Plate A5.2: Float inverted to show the water intake pipe. An aerator is in operation in the background (copy of photo courtesy of B.Chan).

Plate A5.3: Aerator unit in place (copy of photo courtesy of B. Chan).

Plate A5.4: Aerator in operation during autumn (copy of photo courtesy of B. Chan).

Plate A5.5: Sign at an access point to Walloper Lake, B.C. advising the public of the risk of thin ice due to aerator operation (photo taken March 25, 1999 by G. Hartman).

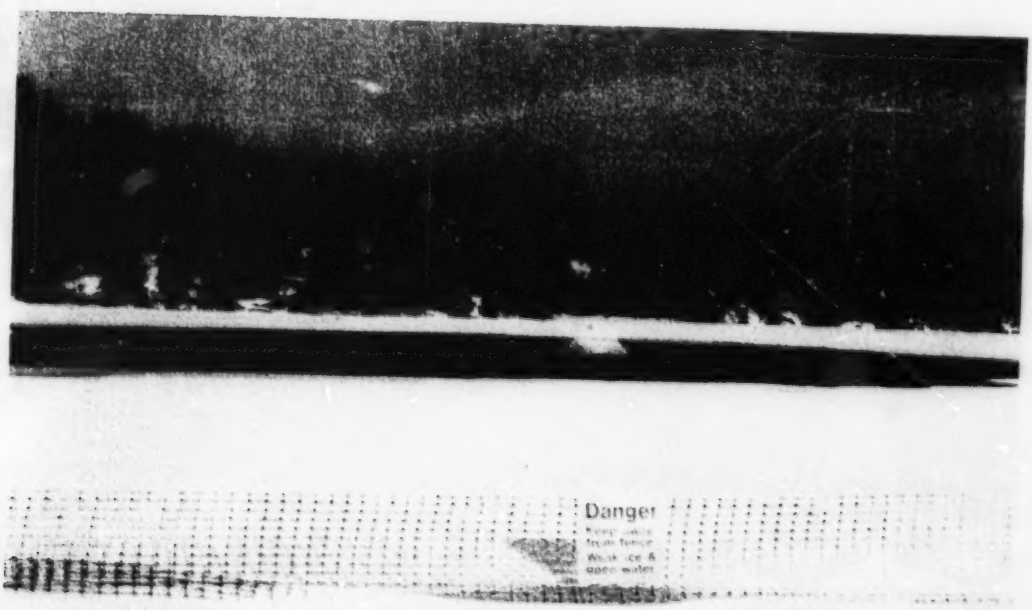


Plate A5.6: Fencing is placed around the hole in the ice (Walloper Lake, B.C.) to protect the public. Warning signs are attached to the fence at regular intervals (photo taken March 25, 1999 by G. Hartman).

APPENDIX 6:
REVIEW OF PROJECTS UNDERTAKEN TO CREATE ARTIFICIAL LAKES, & RAISE LAKE LEVELS OR INCREASE FLUSHING RATES

A6.1 INTRODUCTION

Fisheries habitat or production in lakes can potentially be enhanced by:

i) creating new lakes;
ii) raising water levels; or
iii) providing additional water (to increase lake level, accelerate flushing rates or improve water quality).

Manipulations can be undertaken in both natural lakes and sites developed for hydroelectric, agricultural, mining or other purposes. Most of the information presented is from various Fish and Wildlife Branch Regions in B.C. The number of projects reviewed from each regions is as follows:

Region 3 (Kamloops)	7
Region 4 (Kootenay)	0
Region 5 (Williams Lake)	7
Region 6 (Smithers)	0
Region 7 (Prince George and Fort St. John)	2
Region 8 (Penticton)	5
TOTAL	**21**

Seven mining-related projects were also reviewed from Alberta as the construction of "end pit lakes" is becoming a common procedure for the compensation of lost instream fisheries habitat.

A6.2 REGION 3 (KAMLOOPS)

New information was obtained on three projects in Region 3. Four projects were evaluated on the basis of information presented in *Hartman and Miles, 1995*.

A dam was built on Johnson Lake, above Adams Lake, for water storage for a mine. Fish cannot reach spawning habitat downstream from the dam. An original fishway on the dam did not work well and was re-built. It is not known how effective the project was.

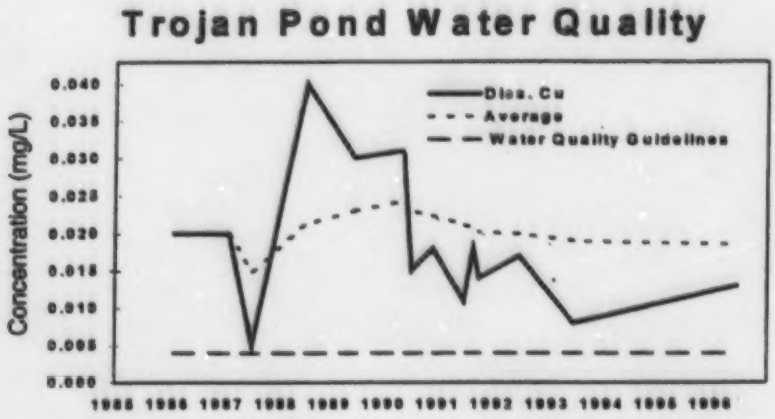
A dam was built on Peter Hope Lake in 1937 to store water for irrigation and cattle. A 2 m draw-down of the lake dried up productive littoral areas with adverse effects on fish. Ninety percent of the water leaving the lake drained into the earth, preventing it from reaching the ranch's irrigation and watering locations. In 1994 a well system was constructed for the ranch in exchange for stable water levels on the lake *(Anonymous, no date)*. The water level in the lake is now stable and a large littoral zone is available. The project is rated as an outstanding success *(B. Chan, pers. comm.)*.

A dam was constructed on Beaverhouse Lake in about 1974 or 1975. This dam has two benefits. It stores water for future use in Tunkwa lake and it increases the water level in Beaverhouse Lake. Both of these contribute to improved production of fish. This project is rated as a moderate success *(B. Chan, pers. comm.)*.

Diversion pipes were built to provide extra water in Walloper, Joyce and Isabele Lakes in order to reduce the potential for winterkill. Initial construction costs were high and the pipes need maintenance and must be drained in the fall. Despite these drawbacks, the projects have been rated as an outstanding success.

Copper mining activity in the Highland Valley near Logan Lake in BC resulted in the loss of 4 small valley bottom lakes. In 1983, the BC government gave Cominco permission to remove three of these after the company agreed to fund an endowment which would pay for future fish and wildlife enhancement projects within a 40 mile radius of the valley. In order to remove the fourth lake, Highland Valley Copper signed an agreement in 1988 to create a replacement fishery in Trojan Lake, a former tailings pond operated by Bethlehem Mine. Detailed monitoring has been undertaken at this site. The results are summarized below as this work is potentially relevant to proposed minesite compensation projects.

The Trojan tailing pond was constructed in 1982 and operated until 1989 when the Bethlehem concentrator ceased operations. The pond has a surface area of approximately 34 hectares, 4 km of shoreline, an average depth of 6.5 m and a maximum depth of 11 m. As indicated below, data presented by Highland Valley Copper suggest that the concentration of copper in the water column dropped quickly following decommissioning of the pond. The significance of the pre-1989 data is unknown.



The $CaCo_3$ content of the pond water was 180 mg/L and therefore the level of copper in 1991 (20 µg/L) was felt to be close enough to the recommended level that a fishery might be possible. [1]

Approximately 8,250 rainbow trout fry have been transplanted into the lake from the Loon Creek Hatchery (1,500 in 1991 and 1992, 2,000 in 1993, 2,500 in 1995 and 750 in 1996). After one year, the 1991 stocking had gained an average of 250 g, they gained another 850 g in 1992 and a further 1,170 g in year 3. Summary statistics on fish size and condition are shown below:

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1 Note data in APPENDIX 1 suggest that required Cu concentration in water with 180 mg/L $CaCO_3$ is 6 µg/L. The graph presented above, from *Hamaguchi (1997)* indicates a guideline of 5 µg/L.

RAINBOW TROUT COLLECTED AT TROJAN POND										
Year	Average Length (mm)	Average Weight (grams)	Age (Yrs)	Sex	Maturity (1-7)	Gonad Weight	Liver Weight	GSI (%) *	LSI (%) **	K ***
1992	306	593.8	2.0	6-M	N/A	16.7	6.5	2.98	1.01	2.04
1993	472	1478.1	2.6	4-F,10-M	5.1	93.7	18.3	5.67	1.22	1.37
1994	450	1431	2	5-F,5-M	4	67.5	18.8	3.43	1.32	1.28
1995	387	1143	1.8	2-F,4-M	4	49.5	18.8	5.23	1.60	1.47
1996	533	1584.5	4.0	5-F,1-M	6	137.2	13.9	5.79	0.91	0.99

[illegible] and gonad weight)
** Liver somatic index (LSI) (%) = 100 x (liver weight/total weight)
*** K or condition factor (K=100 x weight/length³)
[illegible]

[From Hamaguchi, 1997]

Fish measured in 1996 were, on average, 4 years old, had a 533 mm (21 in) fork length and weighed 2,585 g (5.8 lbs). The largest fish sampled in 1996 was 26 in long and weighed 11 pounds.

The metal content of muscle and liver tissue from Trojan Pond is summarized on *Table A6.1*. Muscle tissue collected at Trojan Pond since 1992 shows no abnormal levels of trace metals relative to fish from natural lakes in the area. In contrast, liver tissue collected over the same period show anomalous copper and molybdenum levels.

Dissolved oxygen and temperature profiles from data collected since 1992 indicate that Trojan Pond is turning over annually and not thermally stratifying. The mixing energy from strong winds, combined with the relatively shallow depth of the pond, ensure that dissolved oxygen concentrations are near saturation throughout the growing season.

Lake bottom sediment sampling in 1997 indicated that Trojan Pond had a much smaller buildup of organic material in comparison to surrounding lakes and that many years of biological growth would be required before concentrations of carbon and organic material would resemble a natural system.

Riparian re-vegetation trials are presently being undertaken. It is Brent Densmore's opinion *(pers. comm.)* that nutrients are leaching into the lake from the applied fertilizer and bio- solids. This may be enhancing lake productivity.

Highland Valley Copper has allowed a 2 week long catch and release fishery in September since 1995. Hundreds of fly fishermen have participated and Trojan Pond is gaining a good reputation as a trophy fishery. [All after *C.E. Jones and Associates Ltd., 1996; Hatfield Consultants Ltd., 1997 and 1998 and Hamaguchi, 1997* and *Hamaguchi, pers. comm.*]

A6.3 REGION 4 (KOOTENAY)

No projects were reviewed in this area.

A6.4 REGION 5 (WILLIAMS LAKE)

Information was obtained for eight sites in Region 5 where the water levels were raised. These are Fletcher Lake, Tete Angela Creek, Bringham Dam and Nina, Morehead, Puntzi, Bootjack and Polly Lakes.

Fishery production in Fletcher Lake, about 20 km south of Hanceville, has been enhanced by the combination of a dam on Fletcher Lake, water diversion and spawning habitat construction. The diversion and improved flow through Fletcher Lake is believed to have reduced winterkill risk. The integrated project is rated as being an outstanding success *(M. Lirette, pers. comm.)*.

Tete Angela Creek was diverted through a new channel to improve the water level in lakes in the Seven Sisters group. The diversion was built in the 1950's and reconstructed later. During years of high snowmelt the lakes are filled, step-wise, from the diversion downward. In low flow years the lakes do not fill all the way along the series. The by-pass channel has failed twice. Trout enter the lower part of the diversion and may spawn there. The lakes in the Seven Sisters chain contain only trout so fry produced in the diversion should survive and contribute to the fishery. The project has been given a moderately successful rating *(M. Lirette, pers. comm.)*.

Bringham Dam, built about mid 1950's, raised the water level on Dog Creek at a site where there was originally a very small lake. The spillway deteriorated and was rebuilt in the late 1980's. The original use was for irrigation, however, the impoundment now produces a small number of large rainbow trout. The project was successful for increasing trout fishing opportunities but there were operational problems because fish could not move easily between the outlet stream and the impoundment. For this reason the project is deemed to be a limited success *(M. Lirette, pers. comm.)*.

Nina Lake was originally built in the mid-1930's to store water for placer mining. The dam was abandoned, then taken over by the Fisheries Branch and re-built. Water level is now held constant and the project supports a light fishery. Construction of a new spillway permits spawning movements to the outlet creek so fish now spawn in both the inlet and the outlet. This project is considered an outstanding success *(M. Lirette, pers. comm.)*.

Morehead Lake, where there was originally a small lake/meadow complex, was dammed in 1899 and raised about 7.5 m to provide water storage for hydraulic mining. The original creek and outlet-spawning habitat was lost. The dam and spillway was re-built by the Ministry of Transportation and Highways in 1978. The lake provides some sport fishing, however, there is competition from non-sport fish in it, there is no outlet spawning and beaver dams inundate the inlet spawning area. Stocking programs may require one- year old trout. The project is considered a limited success.

Puntzi Lake was raised with a 1 m dam in 1958. The Fisheries Branch took the project over in 1960. Water level was below the dam in the 1980's and it served no function. The dam was repaired in 1989 but high water in 1995 went over it and flooded private land. Shore erosion occurred during high water periods but it was not severe *(M. Lirette, pers. comm.)*. The fisheries benefits from raised water levels on Puntzi Lake are not presently known and the projects has therefore not been rated.

A dam built at the outlet of Bootjack Lake in 1897 has redirected stream flows through a diversion channel into an adjacent watershed. Lake levels were raised about 1 metre and the 100-year old outlet is now thought to support an improved sport fishery. The actual fisheries benefits of this project are, however, unknown and the project has not been rated *(M. Lirette, pers. comm.)*

A project on Polley Lake has been under consideration. A dam was planned for construction on the outlet stream to raise the lake level for flow augmentation for both mining and fisheries purposes. The benefits of such a project for fisheries have yet to be determined *(M. Lirette, pers. comm.)*.

A6.5 REGION 6 (SMITHERS)

No projects were reviewed in this area.

A6.6 REGION 7 (PRINCE GEORGE AND FORT St. JOHN)

We reviewed 2 projects which increased water levels in lakes in Region 7.

The Shesta Lake dam project was carried out to raise the water level and improve limnological conditions for trout. The water level was raised 1.5 m and the area of the lake, 59.6 ha, was increased by 1.3 ha. The earth-fill dam was raised and an engineered concrete spillway and fish ladder were built in 1985-86. The structure was not stable and it moved 10 cm. In 1991 rip-rap was added to stabilize it. In 1996, the Water Management Branch required that the structure be removed. The project was not successful. It failed physically and the catch of the 15 to 22 cm long stocked trout was very low. The large littoral area, warm water temperatures and competition from non-sport species made the lake unsuitable for trout. The projects is therefore rated as a failure *(D. Cadden, pers. comm)*.

A dyke was built in 1970 on the outlet of Inga Lake, 74 km north of Fort St. John, to store water for injection and gas plant cooling. The dyke deteriorated and was rebuilt in a joint project effort between MOELP, Ducks Unlimited, West Coast Energy Inc., and B.C. Hydro *(T. Euchner, pers. comm.)*. The rebuilt dyke raised the water level 0.5 m. This dam was surfaced with cobbles and rip-rap (on the lake side) and provided with a sheet-pile spillway *(T. Euchner, pers. comm.)*. Increased water levels are believed to have helped reduce winterkill risks. However, the weir and spillway do not permit fish easy access back to the lake. The spillway is now screened, but the screens plug with floating vegetation. Inga Lake is aerated and has a spawning channel on it. The effects of these three activities make it difficult to determine the fisheries benefits arising from the raised lake levels. On the basis of the presently available informaton, the projects is deemed to be a moderate success *(D. Cadden, pers. comm.)*.

A6.7 REGION 8 (PENTICTON)

We reviewed five projects from Region 8 in which water levels were increased to improve fish production.

In 1958 or 1959, a rancher was licensed to build a dam on Echo Lake, east of Winfield. The original dam held the water level about 1 m above the original lake level. The rancher abandoned the license and the Water Management Branch ordered the old dam removed. It was re-built in 1988 but there were still problems with it *(B. Jantz, pers. comm.)*. In 1997 the Habitat Conservation Fund (HCF)supported a project to re-build the dam and increase the water level an additional 1 m. This reconstruction increased shoal area with positive benefits for fish. Fish that leave via the outlet still have some problems returning. Winterkill may have occurred before the dams were built on the lake but it does not now. This project is rated as moderately successful *(B. Jantz, pers. comm.)*.

Ducks Unlimited, the provincial Habitat Conservation Fund and MOELP have all collaborated in the development of a dam and increased water level on Kidd Lake. The lake was originally raised by a beaver dam. In 1993 Ducks Unlimited constructed a dam on the lake *(Barnett, 1992)* which expanded the available habitat. However, the increased littoral area created a risk of winterkill which subsequently required aerating the lake. This project, in combination with aeration, is deemed to be an outstanding success *(S. Matthews, pers. comm.)*.

Beavers caused the first water level increases in Rampart Lake. A fish and game club removed the dam which had been built by beavers and constructed a new one. This structure was not effective. In about 1990, the Fish and Wildlife Branch rebuilt the dam and raised the water level back to the original beaver dam level *(S. Matthews, pers. comm.)*. Additional shoal area was created at each end of the lake, however, this change has not increased the risk of winterkill. The MOELP Fisheries Branch assumed that this project has had a positive effect. However, the actual benefit is unknown and no rating has been assigned *(S. Matthews, pers. comm.)*.

Harvey Hall Lake, located about 16 km south of Aspen grove, was flooded first by beavers and then again, in the mid-1980's, by Ducks Unlimited who doubled the lake area and created a large littoral zone. Winterkills occur regularly in the lake. The project was successful for duck production but not for fish habitat improvement. It is therefore rated as a failure *(S. Matthews, pers. comm.)*.

Projects involving flow augmentation, lake level increase and aeration have been integrated successfully on Burnell Lake, immediately to the west of Oliver. From 1987 to 1992 the lake level was about 3.5 m below 'normal'. A pipeline was built from Henderson Creek to Burnell Lake in 1993 and operated annually *(S. Matthews, pers. comm.)*. By 1997 the lake level was restored. This project was rated as an outstanding success *(Harris, 1999)*.

A6.8 ALBERTA

A6.8.1West Jarvis Pit, Cardinal River Coals Ltd., Alberta

A 16.2 ha lake (Lac Des Roche) was constructed in a remnant "truck and shovel" coal pit south of Hinton, Alberta. The maximum depth is >70 m and the mean depth is 37 m. One end of the lake is shallow and provided a restricted littoral zone which comprises 5% of the lake area. *Luscar Ltd. et al. (1994)* indicates that Lac Des Roche is "relatively cold and deep with a small littoral zone relative to its area. It is therefore an oligotrophic water body with limited fish production capability".

An outlet spawning channel was constructed in West Jarvis Creek as part of this project. This included placing log structures to facilitate fish access over a distance of approximately 200 m. Brook trout, rainbow trout and bull trout spawned in the outlet channel and resided in the lake. As discussed in *Luscar Ltd. et al. (1994)*, Lac Des Roche "may be the first mountain lake that has become occupied by native fish [Bull trout and rainbow trout] from downstream" and it is producing "a self-sustaining sport fishery". The typical size of Athabasca strain rainbow trout in nearby streams is 15 cm at 4 to 5 years and 30 cm at 8 to 9 years. Fish in Lac Des Roche achieved lengths of 40 cm in the initial period following stocking. *Luscar Ltd. et al. (1994)* suggests that these and other data indicate that Lac Des Roche is "substantially more productive than the stream it replaced".

The presence of both an inflow and an outflow channel is thought to be one of the reasons that winterkill is not a problem. Water quality is not an issue, however, the bio-accumulation of selenium (as selenite or selenate) has been identified as a potential concern which is being investigated. *George Sterling (pers. comm.)* indicates that dissolved oxygen concentrations have not been measured at depths

of greater than 30 m. He suggests that the deep portions of the lake may become anoxic and would therefore be unusable for species such as lake trout. Fisheries production in this lake is also thought to be constrained by the lack of littoral area, physical instability within the littoral zone and by the outlet spawning channel which may make it difficult for juvenile fish to migrate upstream to the lake. For this reason *Rudy Hawryluk (pers. comm.)* rates this project as a limited success. Discussions with *George Sterling* also indicate that it would be desirable to undertake more "landscaping work" at end pit mines, such as Lac Des Roche, which are constructed by truck and shovel to improve the aesthetic experience of fishing these areas. [Information from RL&L Environmental Services Ltd., *Carl Hunt, Rudy Hawryluk and George Sterling, pers. comms.* and *Luscar et al., 1994.*]

Another end pit at this mine has been modified to form Sphinx Lake. It is proposed to divert Sphinx Creek into Sphinx Lake and make an outlet channel some time in the future. At the present time the lake is in the process of being reclaimed and has not been stocked. [Information provided by *George Sterling, pers. comm.*]

A6.8.2 Coal Valley Mine, Luscar Ltd., Alberta

This mine is located south of Edson, Alberta. Two lakes were created in the 1980's in the end pits of former "dragline" coal mines. Lovett and Silkstone Lakes have surface areas of 6.0 and 6.4 ha, respectively. Both lakes are moderately deep (maximum depths are 18.0 and 14.8 m; mean depths are 5.5 and 4.7 m, respectively) and have similar amounts of littoral area (32 and 37%, respectively).

Silkstone Lake has an outlet channel which drops down approximately 30 m to Lovett River. There is no suitable habitat and insufficient water to allow rainbow trout to spawn in this channel. Lovett Lake does not have an outlet. No spawning or rearing channels were built at either site. Both lakes have been given to the Province of Alberta to operate as "put and take" fishery lakes. Approximately 1,200 rainbow trout are stocked annually. Six year old fish have been caught which weigh up to 10 lbs *(Dane McCoy, pers. comm.)*. *Carl Hunt (pers. comm.)* suggests that fish size is likely to decrease as the lake has only been open for fishing for a few years. The present high production may also reflect an initial flush of nutrients from the revegetation and restoration program *(George Sterling, pers. comm.)*.

Sampling indicates biological and chemical conditions are similar to those in Fairfax Lake, a nearly natural system. Selenium levels are presently near or below the detectable limits, however, they are currently being monitored and their effects on fisheries productivity is being assessed.

Factors identified as contributing to the success of this project include the shallow lake depth (≤20 m) and the presence of littoral area ≤3 to 5 m deep which contribute to lake productivity. Fishing pressure is also low because anglers have to walk 1.5 km from the nearest road. Detrimental features include an initial lack of cover which made fish susceptible to predation at the time of stocking and, in Silkstone Lake, a loss of fish escapement through the outlet channel. *Dane McCoy (pers. comm.)* rates both lakes as being a moderate to outstanding success. However, neither lake can produce a self-sustaining population of fish and the rating would therefore be decreased if this criteria was included in the evaluation. For this reason, we have given these projects a moderate rating (although this is not consistent with criteria used by some habitat biologists in B.C.). *George Sterling (pers. comm.)* indicates that the side slopes around these two dragline pits are in the process of revegetation and, in 20 years, it may be difficult to distinguish them from a natural lake. He therefore gives both lakes a positive rating for being an aesthetically pleasing area to fish.

Three more lakes are in the process of being developed at Coal Valley Mine. At least one of these will have inlet or outlet spawning capability. It is presently expected that one of these lakes will be stocked

in 1999. [Information provided by RL&L Environmental Services Ltd., *Carl Hunt, Rick Ferster, Dane McCoy and George Sterling, pers. comms.* and *Luscar Ltd. et al. 1994.*]

A6.8.3 Whitewood Mine, Trans Alta Utilities Ltd., Alberta

Whitewood Mine is located near Wabamun Lake, Alberta. Two small perched lakes were drained to allow open pit coal mining *(Lulman, 1989)*. In compensation, an isolated ground water fed lake (East Pit Lake) was created in the end pit of a depleted coal seam. The lake has an area of 18.5 ha, a shoreline length of 3,500 m and a depth of about 7.8 m. The lake was constructed by "truck and shovel" and the side walls are therefore very steep and there is only a limited shallow littoral area (estimated at approximately 15% of the total surface area). The lake is annually stocked with rainbow trout. The project is in its third or fourth year of operation and fish of up to 8 lbs in weight have been obtained. Sampling indicates the lake is producing a "plethora" of invertebrates *(Cam Bateman, pers. comm.)* and that there are no adverse heavy metal concentrations in the lake sediments, water or fish (muscle or tissues). Dissolved O_2 levels are adequate and the lake is not subject to winterkill.

The Stony Plain Fish and Game Association was extensively involved in the design of this project and has recently taken out a 21 year lease on the lake. East Pit Lake is being managed as a walk-in recreational fishery. Trans Alta is providing a parking lot, rest room and signage.

Future projects might benefit from a larger littoral zone (defined in this project as being less than 1 m deep). On the basis of the results from this project, *Cam Bateman (pers. comm.)* suggests that the littoral zone should ideally be in the range of 25 to 33% of the total lake area. Factors which helped the success of this project included the presence of a ground water source and, most importantly, the community involvement. *Cam Bateman (pers. comm.)* rates this project as being an outstanding success. [Information provided by RL&L Environmental Services Ltd., *Jim Allan, Rick Ferster, Rudy Hawryluk, George Sterling and Cam Bateman, pers. comms.* and *Luscar Ltd. et al., 1994*).

A6.8.4 Forestburg Diplomat Mine, Luscar Ltd., Alberta

> *"In 1977, a final cut at the Forestburg Diplomat mine near Forestburg, has been converted to a 6.2 ha, 7 meter deep lake. The lake is located north of the Battle River approximately 3.0 km from Big Knife Provincial Park. It was first stocked with rainbow trout in the spring of 1980. Water chemistry results obtained in 1979-1981 did not show any trends. Although the dissolved solids content was high (in the range of 2,000 mg/L), it did not affect trout survival and growth. Presently the pond is owned and operated by the County of Flagstaff. Due to the heavy fishing pressure, the pond is stocked on a yearly basis."* *Luscar Ltd. et al., 1994.*

Rick Ferster (pers. comm.) has given this project an "outstanding success" rating.

A6.8.5 Black Nuggett Pond, Dodds Coal Mine, Alberta

This former coal pit is located near Round Hill in Alberta. Black Nugget Pond has a surface area of 7.3 ha and a maximum depth of 5.4 m. It was originally stocked in 1957 despite having dissolved solid concentrations of >900 mg/L, high concentrations of sulphates and meagre densities of plankton and benthic fauna. The lake has been stocked on an annual basis since 1970. Water quality analyses in 1985 indicated continued high dissolved solids (826 mg/L), sulphate (397 mg/L) and nitrate (1.3 mg/L)

concentrations. Levels of dissolved oxygen recorded on various occasions ranged between 6.2 and 9 mg/L. In July 1986, five rainbow trout measuring 340 to 390 mm in length were submitted for mercury analyses. All results were well below the recommended standard of 0.5 mg/L.

The report by *Luscar Ltd. et al. (1994)* does not provide any indication of fish productivity. This project has therefore been tentatively rated as a moderate success. [All information from *Luscar Ltd. et al., 1994.*]

A6.8.6 Cheviot Mine, Cardinal River Coals Ltd., Alberta

This proposed project is located near Jasper National Park. The development plans call for the construction of seven mine pit lakes capable of supporting self reproducing populations of native Athabasca rainbow trout. This project has received environmental approval from the joint Alberta Energy and Utilities Board and the Canadian Environmental Assessment Agency. However, no construction has presently occurred and the project is on hold due to low coal prices and legal intervention of environmental groups. [Information provided by RL&L Environmental Services Ltd., *Carl Hunt and Rudy Hawryluk, pers. comms. and Anonymous, 1997.*]

TABLE A6.1: METAL CONTENT IN MUSCLE AND LIVER TISSUE FROM FISH COLLECTED AT TROJAN POND *(from Hameguchi, 1997).*

MUSCLE TISSUE METAL CONTENT (mg/kg wet weight) IN RAINBOW TROUT, HIGHLAND VALLEY COPPER, B.C. (data are averages)												
Location & Year	**Sample Size**	**Length (mm)**	**Weight (g)**	**Age (yrs)**	**As**	**Cu**	**Fe**	**Pb**	**Mn**	**Hg**	**Mo**	**Zn**
Trojan Tailings Pond												
1996	6	533	1585	4.0	0.02	0.6	8.5	<0.05	0.09	0.097	<0.05	4.02
1995	6	387	1143	1.8	0.02	0.41	3.87	<0.05	0.070	0.046	<0.05	3.86
1994	6	450	1431	2	<0.01	0.27	3.51	<0.02	0.091	0.053	<0.05	4.06
1993	9	471	1495	2.7	<0.01	0.56	5.45	<0.01	0.093	0.032	<0.05	4.29
1992	6	306	594	2	0.02	1.01	8.14	<0.01	0.129	0.043	<0.05	6.19
Ave/Tot	33	433										
Pimainus Lake (Reference)												
1996	6	242	165	2.6	0.01	0.4	6.4	<0.05	0.11	0.057	<0.05	6.02
B.C. Muscle Average (Reiberger 1992a)**												
Average					0.15	0.39	7.50	0.41	0.27	0.09	n/a	4.28
St.Dev.					0.52	0.29	7.76	0.52	0.13	0.05	n/a	1.35

** Reiberger (1992) The average value of metals in muscle tissue from fish samples in 24 uncontaminated lakes in British Columbia. Metals values exceeding the Reiberger average are printed in bold and shaded.

LIVER TISSUE METAL CONTENT (mg/kg wet weight) IN RAINBOW TROUT, HIGHLAND VALLEY COPPER, B.C. (data are averages)												
Location & Year	**Sample Size**	**Length (mm)**	**Weight (g)**	**Age (yrs)**	**As**	**Cu**	**Fe**	**Pb**	**Mn**	**Hg**	**Mo**	**Zn**
Trojan Tailings Pond												
1996	6	533	1585	4.0	0.03	175.2	772	<0.05	1.09	0.103	0.37	36.1
1995	6	387	1143	1.8	0.07	89.2	124	<0.05	1.17	0.042	<0.5	22.8
1994	6	450	1431	2	0.029	154	296	<0.02	1.06	0.049	0.207	26.0
1993	9	471	1495	2.7	0.027	119	345	<0.02	1.18	0.052	0.124	37.8
1992	6	306	594	2	0.017	122	226	0.037	1.68	0.061	0.190	56.5
Ave/Tot	33	433										
Pimainus Lake (Reference)												
1996	6	242	165	2.6	0.05	68.8	160	<0.05	1.01	0.105	0.14	56.6
B.C. Muscle Average (Reiberger 1992a)**												
Average					0.18	51.1	318	0.74	1.57	0.11	n/a	28.8
St.Dev.					0.63	46.8	213	1.88	1.19	0.10	n/a	16.8

** Reiberger (1992) The average value of metals in liver tissue from fish samples in 24 uncontaminated lakes in British Columbia. Metals values exceeding the Reiberger average are printed in bold and shaded

APPENDIX 7:
REVIEW OF PROJECTS UNDERTAKEN TO CREATE SPAWNING OR REARING CHANNELS AT LAKE INLETS OR OUTLETS

A7.1 INTRODUCTION

Many projects have been undertaken in the past two decades to increase spawning gravel area or rearing habitat. A comparatively small number of projects have involved the construction of artificial channels to provide spawning or rearing habitat. In some circumstances, these channels have been constructed simply to allow egg and milt-bound fish to spawn and no attempt has been made to provide conditions suitable for egg development or juvenile rearing.

The number of projects undertaken in each of Ministry of Environment Lands and Parks Regions is as follows:

Region 3 (Kamloops)	11
Region 4 (Kootenay)	5
Region 5 (Williams Lake)	12
Region 6 (Smithers)	10
Region 7 (Prince George and Fort St. John)	5
Region 8 (Penticton)	7
TOTAL	50

Two projects from Alberta have also been identified and discussed.

A7.2 REGION 3 (KAMLOOPS)

We have identified 11 projects in Region 3 where improvements to existing spawning areas or the creation of new areas were conducted. Some of the projects were intended to produce fry for eventual recruitment to the fishery. Others were carried out to get trout to deposit their eggs so the fish would not be egg-bound. These latter projects were done in conjunction with stocking because the numbers of fish going into the lake could be controlled much more precisely in a formula-based stocking program *(B. Chan, pers. comm.)*.

Spawning platforms were constructed in Criss and Shakan Creeks. They were initially effective *(Hartman and Miles, 1995)* but did not succeed in following years. Gravel attracted fish until it was washed out. Both of these projects are now considered as failures *(I. McGregor, pers. comm.)*.

A dam was built on Johnson Lake, above Adams Lake, for mine water storage. This project was intended to assist fish in accessing spawning habitat and to improve the lake level. For a further description see APPENDIX 6, SECTION 6.2, REGION 3.

Artificial spawning channels were constructed at Lac de Roche (1990) and Dutch Lake (1989) and water was pumped into them to attract fish and provide water in which to spawn. The channels were run all summer. A 5 HP, single-phase motor provided power for the pump at Dutch Lake and cost about $170/mo to operate. These operations are considered as outstanding successes, however, it was crucial that the pumping did not stop *(B. Chan, pers. comm.)*.

Spawning channels were built at Lac La Jeune and Roche and Logan Lakes to get trout to deposit eggs and thus avoid the problem of egg-bound fish. Water was supplied to the channels by pump. The channels were shut down after spawning and no fry survived to enter the lakes. At Roche Lake pumping started about the time the ice melted and continued for 1.5 months. At Lac La Jeune the spawning channel provided a strong tourist attraction. Channels were built with pools in them so that in the event of power failure the trout would have a temporary refuge. A 30 m channel at Logan Lake cost about $20,000 for construction and $170/mo for operation. All three of these projects are rated as outstanding successes *(B. Chan, pers. comm.)*.

Three spawning channels were constructed at Trojan Pond by Highland Valley Copper. This site is described in some detail due to its potential relevance to other minesite development or compensation projects.

> *"The first one relied on a pumping system to get water into a spawning channel. The fish started using the pumped system on May 25th, 1994 and were able to use it until June 3rd when the pump ceased. The incident illustrated the importance of not relying on a man-made water source. The second channel was built to rely on the spring runoff flow into Trojan Pond. Unfortunately, not enough water reached the spawning channel during the spawning season as a result of excessive seepage losses along the diversion ditch and spawning channel.*
>
> *Construction ... started on a third spawning channel [in 1995] which will rely upon the natural flows of Trojan Creek and will be operational for the spring of 1995. This spawning channel may not attract fish every year because of the variability of the spring runoff times and flows. This inconsistency may contribute to the overall sustainability of Trojan Pond by limiting the overall fish population and enhancing the growth of larger fish." (from Highland Valley Copper, 1994)*
>
> *"The [completed] 275-metre long channel consists of riffles and pools alternating along its length. Deep pools were designed into the channel to provide quiet, resting areas for the spawning fish and to help the fish survive during low water flow. The channel was dug at a 1 - 1.5% grade to create a flow rate that would provide a sufficient supply of oxygen to the eggs. In order to optimize water flow through the gravel and to prevent the fish from injuring themselves, water-washed, rounded river gravel from the South Thompson River was placed on the channel bottom. Given the large size of fish that had spawned the previous year, a gravel size of 4 to 8 cm was used. Stumps and logs were placed along the channel bed to more closely resemble a natural spawning channel."*
>
> *"The channel was fed water from a small collection pond constructed to capture and retain natural water from nearby Trojan Creek and its tributary. Water flow is controlled using a butterfly valve on a 10-inch pipe passing through the pond's retaining dam. Flow rate is set at 200 gallons per minute during the spawning season and reduced to 150 after the spawning fish have returned to Trojan Pond."*
>
> *" A two-compartment fish trap captures the fish when they enter the spawning channel and when they return to the lake. Fish captured on their way upstream are weighed, measured and tagged. The downstream trap allows spawning times to be calculated."*

"By 1995, 136 fish used the spawning channel, producing thousands of fry. By 1996 more and even larger trout (length and weight) were using the channel, as indicated below:"

FISH TAGGING PROGRAM, TROJAN POND SPAWNING CHANNEL		
PARAMETERS	**1995**	**1996**
Total Number of Fish	136	179
Number of Fish Tagged	114	174
Ratio of Females to Males	54% Female, 46% Male	64% Female, 36% Male
Average Length	560 mm (22 in)	563 mm (22.2 in)
Average Weight	2.108 g (5.6 lbs)	2.516 g (6.74 lbs)
Average Age	3	3.4
Longest Fish	25 inches	27 inches
Heaviest Fish	8 lbs 3 oz	10 lbs 9 oz

All from Hamaguchi, 1997

The first two projects have been rated as failures and the third is assumed to be an outstanding success.

A7.3 REGION 4 (KOOTENAY)

Five gravel introductions, one spawning channel and one rearing habitat project for trout were reviewed with staff in Region 4.

Gravel was placed in Staples Creek (near Premier Lake), Lavington Creek (a tributary to Finlay Creek), Hall Creek (northwest of Invermere) and in a tributary to Connor Lake.

In Staples Creek logs and, more recently, rows of rocks were placed across the channel to hold the gravel pads. There are lakes at the headwaters of Staples Creek so the flows were stable and also low. The structure now works well and has been rated as an outstanding success *(B. Westover, pers. comm.)*.

In Lavington Creek, gravel and cover material were placed in the creek in a meadow area. Initial information reported in *Hartman and Miles (1995)* rated the project as successful. However, by 1998 banks were eroding and log structures were collapsing into the stream. The project may provide cover, but it does not now succeed in providing spawning habitat. It is now rated as a failure.

Hartman and Miles, 1995 rated the gravel placement project at Hall Lake as moderately successful. There is no more current information.

There are four spawning-gravel platforms in the tributary to Connors Lake which were put in by hand. They are now well used and considered moderately successful. However, the gravel may eventually have to be replenished because the spawning cutthroat trout displace it downstream *(B. Westover, pers. comm.)*.

The Whiteswan Lake rainbow trout spawning channel has been improved since the time of the survey by *Hartman and Miles (1995)*. Egg-to-fry survival is still lower than desirable. This may be caused by nest superimposition *(B. Westover, pers. comm.)*. The project is now considered moderately successful.

A7.4 REGION 5 (WILLIAMS LAKE)

Twelve spawning habitat improvement projects were identified during interviews with staff in Region 5. Some of these projects were previously discussed in the report by *Hartman and Miles (1995)*, however, the conditions and outcome in each of them are now somewhat different.

Four gravel spawning platforms built in conjunction with a water diversion project into Fletcher Lake have worked well and this project is considered an outstanding success *(M. Lirette, pers. comm.)*.

Gravel placement in Eureka Creek, an outlet stream from a small lake about 15 km south of the eastern end of Horsefly Lake, successfully provided spawning habitat for trout. This project worked because streamflow was adequate throughout the year and the lake to which the fry migrated was a mono-culture trout lake. This project is rated as a moderate success.

Gravel for spawning trout was placed in the lower reaches of small tributaries to Chaunigan Lake, about 20 km north of Fish Lake. Gravel was placed in tributaries where flow was reported, however, these tributaries are frequently dry during summer. Project success and fry recruitment during the 1990's was believed to be dependent upon rainfall and improved streamflow *(M. Lirette, pers. comm.)*. The value of the habitat improvement may be relatively small and the project is rated as a limited success.

A number of gravel platforms have been constructed in Watch Creek, an inlet tributary to Green Lake. The stream discharge is variable and flows are frequently inadequate for the production of yearling trout. This project is therefore rated as a limited success.

Gravel was placed in Dog Creek at the inlet to Gustafson Lake. No hydrological assessment was done before the project and the stream dries up during most summers. Natural production of fry from the project has not been dependable so the lake is stocked annually. A storage dam on the outlet of Gustafson lake precludes outlet spawning. This project has been rated as a failure *(M. Lirette, pers. comm.)*.

Gravel platforms were constructed in Holley and Hallis Creeks, inlet tributaries to Dragon Lake near Quesnel in May, 1980. The spawning areas within Hallis and Holley Creeks were increased by 375 and 20 m^2 respectively. Gravel was placed in a number of other small tributaries to Dragon Lake. The projects in Hallis and Holley Creeks improved production in 1979. However, there have been problems with the volume and quality of water in the creeks due to impacts by cattle. The projects are periodically at risk due to inadequate low flows and require maintenance *(M. Lirette, pers. comm.)*. During years when there are adequate flows, large fish enter the small creeks and become stranded. They are then poached or taken by bears. Some of the small streams are now screened off to prevent spawner access. This project is thought to be a limited success.

Existing gravel was scarified and extra gravel was added in the Little Horsefly River. This project was done primarily for kokanee and its success is not known.

Gravel was placed in the inlet and outlet of Chimney Lake *(Demers et al., 1979)*. The lake is regularly stocked so a major value of the project was that it ameliorated the problem of "egg-bound' fish. However, flows are not dependable and fry do not always survive to enter the lake *(M. Lirette, pers. comm.)*. The project is considered moderately successful.

Gravel was placed in the outlet of Bridge Lake and the large woody debris was removed in 1985. The problem with this project was that the trout did not need more spawning gravel. They needed rearing space and year round flows as the outlet creek goes dry in some years. Unfortunately, the rearing habitat was destroyed during construction. Due to the presence of non-sport fish in the lake, one-year-old fish not fry recruitment were also required. The project was therefore successfully constructed but the biological benefits are questionable *(M. Lirette, pers. comm.)*. This project is therefore considered to be a failure.

Gravel was placed at the inlet of Morehead Lake, about 10 km west of Likely. A water storage dam was built on the outlet of the lake in 1899 which eradicated any potential outlet spawning areas. In addition, beaver dams in the inlet creek have further reduced the available spawning areas. There is competition from non-sport fish in Morehead Lake, so the young trout entering it should be one year old fish rather than fry *(M. Lirette, pers. comm.)*. This project did not improve the Morehead Lake sport fishery and is therefore rated as a failure.

The fish enhancement at Eighty-three Creek was one of the earliest attempts to create a spawning channel for trout in the interior of British Columbia. The developmental and early stages of the project were described in *Taylor (no date)*. There were a number of difficulties with the project. Green Lake has very high pH value (9.3) and supported large populations of non-sport fish. As a consequence, one-year old fish were more suitable than fry. Flows in the creek were inadequate to sustain a year round water supply in the channel. Water storage for fish production within the basin was objected to by the Department of Agriculture and water pumped from two drilled wells at the top of the channel could not provide adequate flows. The project was abandoned in the mid-1970's *(M. Lirette, pers. comm.)*.

A7.5 REGION 6 (SMITHERS)

Ten projects to enhance spawning habitat were identified in Region 6.

Gravel replacement and culvert removal were carried out in Silverthorn Creek. Difficulties occurred with the gravel replacement and the project had to be re-done in two years. Soft clay banks sloughed in and buried the gravel and the stream widened. The gravel had to be excavated and the creek deepened to re-establish the original cross-section shape. The project is now moderately successful *(S. Hatlevik, pers. comm.)*.

Gravel placement in the outlet of Island Lake was successful at the time of the review by *Hartman and Miles (1995)*. It is believed that logging road and bridge construction have damaged the project somewhat *(S. Hatlevik, pers. comm.)* and the present success is unknown.

Gravel placement at the outlet creek of Helene Lake was an outstanding success. About 12 spawning pads were built to create 200 lineal metres of spawning habitat. The water is clear and there are no other places for trout to spawn. One thousand to 1,500 trout have been seen on the area and the only concern now is that the area may produce too many fry *(S. Hatlevik, pers. comm.)*.

A large trout spawning improvement project, costing $100,000, was built on Nadina River by the Federal and Provincial Governments. The river was blocked off, compacted gravel and sand was excavated and new gravel was put in *(S. Hatlevik, pers. comm.)*. This project is believed to be moderately successful, but data that would permit production comparisons with pre-project conditions are not available.

Gravel was placed in Bartok Creek, an outlet stream of a lake that was previously barren of trout. The project is believed to be of limited success. Trout are present in the lake, however, they may be reproducing in an inlet tributary.

Gravel was placed in Tagetochlain (Poplar) Creek, an outlet tributary that runs into Nadina River. The project was done in the autumn and large numbers of trout were not seen in the following spring. However, the gravel is extensive and deep and it is considered that the project will become more successful with time *(S. Hatlevik, pers. comm)*. It is presently rated as a moderate success.

Gravel was placed in 4 small groundwater tributaries to Lakelse Lake. Logging impacts had caused gravel loss and degradation. The project was rated as having limited success *(Hartman and Miles, 1995)*. There is no further information on it.

Beaver dams were removed and gravel was placed in Seeley Creek. The creek, which had a gradient of 3.5 to 5% was too steep and the project was a complete failure *(S. Hatlevik, pers. comm.)*.

Two gravel placement projects were done on Chicken Creek, a channel that connects Kathlyn Lake to the Bulkley River. Gravel pads, held in place by rows of rocks placed across the creek, were washed out of the lower creek during freshet. The gradient was too steep for the structure to be stable *(S. Hatlevik, pers. comm.)*. In the upper part of Chicken Creek, gravel placed in a low gradient section of creek with soft banks was buried in mud. In this location, the banks were unsuitable for the project *(S. Hatlevik, pers. comm.)*. Both are rated as failures.

A7.6 REGION 7 (PRINCE GEORGE AND FORT ST. JOHN)

Five spawning habitat enhancement projects were carried out in Region 7.

Gravel was placed at the outlet of Purden Lake in the late 1970s. A sportsman's club and the Fish and Wildlife Branch did the work. The project was not followed up and the present success is unknown.

Reverse gravel spawning platforms were built in Corkscrew Creek one km upstream from Nulki Lake, near Vanderhoof. The project was reported as successful in *Hartman and Miles (1995)*. However, the gravel was placed in a low gradient stream reach and beavers have since dammed and flooded the gravel areas. New spawning sections, further up stream, may be opened up. Effort is now being made to provide access through the beaver dams that cover the project *(D. Cadden, pers. comm.)*. The project is presently considered a failure.

Reverse gravel platforms were built in Bateman Creek, an inlet creek on Eaglet Lake. The creek is subject to freshets and most of the 32 platforms have been eroded away. Some spawning still occurs in the enhanced section of creek. However, logging and mining upstream have degraded the stream. Eaglet Lake supports populations of burbot and squawfish so if the spawning area produces fry, they run a high risk of being eaten upon entering the lake *(D. Cadden, pers. comm.)*. The Bateman Creek project was rated as being of limited success in *Hartman and Miles (1995)*. It is now less successful.

An artificial spawning channel, supplied with water by a 10 HP irrigation pump, was installed at Inga Lake to allow trout to deposit their eggs and not be egg-bound. The channel is 100 m long and 1.5 m wide. It contains refuge pools in case of pump failure. It may be used by as many as 300 trout. After the fish have deposited their eggs and returned to the lake the pump is shut off. The project serves its purpose effectively and is considered an outstanding success *(D. Cadden, pers. comm.)*.

Spawning channel construction and gravel placement was carried out between Chubb Lake and a small upstream lake to prevent trout from becoming egg-bound. When snowpacks were adequate, flow in the channel attracted 800 to 1,000 trout. However, during a year with low snowpack, the channel would go dry and fish had to be salvaged. The lake is now stocked with sterile trout and the channel project has been abandoned *(D. Cadden, pers. comm.)*.

A7.7 REGION 8 (PENTICTON)

Seven spawning enhancement projects were reviewed in Region 8. The primary emphasis is on kokanee production in six of these channels.

Gravel placement in Winfield Creek was reported as an outstanding success in *Hartman and Miles (1995)*. The project is now rated as a limited success. It requires labour-intensive maintenance in which gravel has to be flushed annually *(S. Matthews, pers. comm.)*. Rainbow trout use of the creek is marginal.

Middle Vernon Creek required both channel stabilization and gravel placement. In 1987 the channel was lined with rip rap and filter cloth and spawning gravel was placed in it. Both kokanee and rainbow trout are reported to use the creek. The project was reported in *Hartman and Miles (1995)* as an outstanding success. It is still successful but the gravel becomes silted-in every one or two years and maintenance is required *(S. Matthews, pers. comm.)*

Mission Creek, at Kelowna, has had a long history of use for irrigation and a more recent history of attempted use for fish production. The Smith-Alphonse Dam, a diversion structure that was expanded over the years and used with various fishways, was removed in 1981. The main channel where the diversion weir had been was armoured with large rock and cobbles. Some rocks were placed in the channel to improve trout rearing conditions. The original diversion channel was converted into the Mission Creek spawning channel in the mid-1980's. This channel was intended, in part, for rainbow trout use *(S. Matthews, pers. comm.)*. The history of kokanee production in the Mission Creek channel was reviewed by *Redfish Consulting Ltd. (1999)*. The spawning channel which was built in 1987 was re-built in 1996. Gravel loss during freshets is a chronic problem. The drainage is considered to be too large and prone to freshets to permit enhancement measures to succeed. The project is now rated as a failure *(S. Matthews, pers. comm.)*.

In 1992 approximately 65 gravel platforms for kokanee were constructed in 600 m of Peachland Creek. Earlier work had been done in the creek by a local fish and game club. During the expansion of the platform construction program there were problems of sediment deposition. In 1988, up to 30 cm of sand was deposited on the enhanced section during a heavy rainstorm. Sediment comes from sections of the creek above Hardy Falls. About 65 sediment collection structures, spaced 20 to 30 m apart, have been built in part of the gully system above the falls to stop sediment transport to the enhancement area. In spite of difficulties, this project was rated as an outstanding success *(Hartman and Miles, 1995)* and is still regarded as successful *(S. Matthews, pers. comm.)*.

Gravel was placed at 4 sites and access for kokanee was improved in Penticton Creek. Parts of the creek had previously been channelized and lined with concrete. It is difficult to evaluate the project because there have been hatchery releases of fry in the creek and conditions in Lake Okanagan may confound other effects. It is presently rated as a limited success *(S. Matthews, pers. comm.)*.

Once a year a sportsman's club place short patches of gravel in the upper end of a 400-500 m long section of Trepanier Creek which is accessible for kokanee spawning *(S. Matthews, pers. comm.)*. This project has had limited success because the creek is "flashy" in the spring and erodes the placed gravel.

Also, water is low in the autumn. Run size and return success are confounded by other conditions in the creek and lake *(S. Matthews, pers. comm.)*. The project is considered to be a limited success.

Four spawning gravel platforms supported by rock or timber weirs were placed in the lower end of Powers Creek, south of the community of Westbank. This project was done primarily for kokanee. A ladder has been built in a chute in the lower part of the creek to provide access for fish *(S. Matthews, pers. comm.)*. The project requires annual maintenance and is considered to be of limited success.

A7.8 MAJOR SPAWNING FACILITIES – PRIMARILY FOR KOKANEE (MOSTLY IN THE KOOTENAYS)

Six channels have been constructed for kokanee spawning *(Redfish Consulting Ltd., 1999)*. Most of these channel are in the Kootenays. Although spawning use of the channels by rainbow trout is not significant, they are reviewed because they indicate the level of success that may be achieved in artificial facilities that are well designed and maintained. They also provide a good indication of the major considerations involved in the construction and maintenance of spawning channels.

Spawning channels in Meadow Creek, north of Kootenay Lake, and Hill Creek, Upper Arrow Lake, were built in compensation for B.C. Hydro developments that affected Kootenay and Arrow Lakes. Channels in Bridge Creek (located near Revelstoke), Kokanee and Redfish Creeks (located in the west arm of Kootenay Lake) and Mission Creek (a tributary to Okanagan lake) were built with Habitat Conservation Fund money *(Redfish Consulting Ltd., 1999)*. All six channels have performed well with average egg-to-fry survivals over 25%, about five times that of natural stream survival. Five of the six channels met targets for egg-to-fry survival. Meadow Creek met the target level between 1986 to 1998 after improved maintenance practices were initiated. The following scores were obtained by rating the projects on the number of fry produced, the number of spawners, egg-to-fry densities, egg-to-fry survival and the optimum number of fish: Bridge Creek 11/25, Kokanee Creek 25/25, Hill Creek 22/25, Meadow Creek 21/25, Mission Creek 13/25, and Redfish Creek 24/25 *(Redfish Consulting Ltd., 1999)*. Mission Creek channel has not been successful in maintaining adult kokanee numbers. This is believed to be the result of unfavorable lake conditions.

All of the channels require annual operational management. Five of the channels require gravel cleaning. Mission Creek is cleaned hydraulically and Hill, Meadow, Redfish and Bridge Creeks are cleaned by scarification with tractors. Management of water supply, fencing and control of fish is required in three of the channels.

The construction and maintenance of spawning channels for rainbow trout may be more complex than for kokanee. The presence of predators and competitive species in some lakes would require the production of 1+ trout rather than fry. Channels built in inlet streams, from which fry go immediately to a lake where there are predators and competitors, may not be very successful. If the channel constructed is to be used to produce 1+ trout, water quality, supply and hydrological regime must be suitable year around. However, the experience gained in constructing, operating and evaluating spawning channels, for kokanee, ought to be of value if such major facilities are to be built for rainbow trout.

A7.9 ALBERTA

A7.9.1 West Jarvis Pit B6, Luscar Ltd., Alberta

As discussed in APPENDIX 6, Lac Des Roche was constructed in a remnant coal pit south of Hinton, Alberta. A spawning channel was constructed at the outlet of the lake. Log cribs and gravel were placed to

provide spawning habitat. The riparian vegetation was successfully established by excavating and transplanting entire "clumps" of live willows. Brook trout, native Athabascan strain rainbow trout and bull trout have successfully spawned in the channel. However, there is concern that the Athabascan strain of rainbow trout (which are comparatively small fish and typically inlet spawners) may not be able to successfully migrate upstream to the lake *(G. Sterling, pers. comm.)*. On this basis, the channel is assumed to be a limited success. [Information provided by R.L&L Environmental Services Ltd., *Carl Hunt and George Sterling, pers. comm.*]

A7.9.2 Coal Valley Mine, Luscar Ltd., Alberta

This mine is located south of Edson, Alberta.

As discussed in APPENDIX 6, the outflow channel from Lovett Lake drops approximately 30 m to Lovett River. There is no suitable habitat nor sufficient water to allow rainbow trout to spawn in this channel. *Luscar Ltd. et al. (1994)* suggests that the low survival rate of fish in Lovett lake was partially caused by "the escapement of fish through the outflow channel. In 1993 Coal Valley mitigated the problems by introducing additional escape cover (rock and brush piles) and modifying the outflow channel." However, a recent site inspection indicates that this work has not been successful and the channel is therefore rated as a failure *(G. Sterling, pers. comm.)*. [Information from *Luscar Ltd. et al., 1994* and *George Sterling, pers. comm.*]

APPENDIX 8
REVIEW OF PROJECTS UNDERTAKEN TO CREATE ECOLOGICALLY EFFECTIVE DIVERSION CHANNELS AROUND PITS, ROCK DUMPS AND SETTLING OR TAILINGS PONDS

A8.1 INTRODUCTION

A total of 11 projects were located in which diversion channels were created or are proposed as a result of mining activity. Five sites are in B.C., two are in Yukon, three are in Alberta and one is in the NWT. Many additional sites likely exist and further effort is required to provide an adequately sized data base. Each of the identified projects is briefly discussed.

A8.2 LINE CREEK MINE, LUSCAR LTD., B.C.

Sections of South Line Creek in the East Kootenays have been reconstructed due to mine site development. A diversion channel was constructed in 1984 or 1985. The grade was steeper than the pre-existing channel and drop structures were therefore placed to control water velocities and provide scour holes for fish. This section of channel was subsequently buried and another section of stream was relocated. Fisheries structures were designed by Piteau Engineering based on typical designs prepared for use in Alberta *(Lowe, 1992)*. The June 1995 flood caused the alluvial sections of the diversion channel to increase in width 3 or 4 fold. All fisheries structures were destroyed and they have not been rebuilt. This projects is therefore deemed to be a failure. [Information provided by *Jim Lant, Jim Allan, pers. comms. and Line Creek Resources Ltd. 1992, 1993.*]

A 600 m long section of Line Creek was diverted in 1993. The channel was armoured with rock and tree revetments were placed to provide fisheries habitat. The tree structures were subsequently destroyed. The channel has provided spawning habitat for bull trout and the number of bull trout has increased following this work. The removal of a barrier has improved access to upstream spawning habitat. However, the adoption of catch and release fishing regulations is felt to be the principal reason for the increase in bull trout numbers. This project is rated as being a moderate success.

A8.3 FORDING COAL MINE, FORDING COAL LTD., B.C.

A section of Fording River was diverted in the late 1970's. Nine drop structures were placed to control water velocity and provide fisheries habitat as the reconstructed channel had a reduced length and an increased slope. This work was reviewed by Pisces Environmental Consulting Service following the June 1995 flood. Eight of the nine structures had been destroyed, the channel had scoured to near bedrock and only a few cutthroat were seen. This project is therefore rated as being a limited success *(Jim Allan, pers. comm.)*.

An approximately 900 m long section of Henretta Creek was diverted through two corrugated steel pipes (diameter 1.8 and 2.2 m) due to construction of the South Pit Mining Area. Pre-production reports *(Fording Coal, 1991)* indicate that:

> *"After mining is completed in 1996, a reclaimed channel for Henretta Creek will be constructed adjacent to the diversion dyke and culvert diversion which are planned to be kept intact for a period of two (2) years during the post mining period. This is to allow for the option of diverting Henretta Creek back into the culvert during the winter low flow period if nitrogen concentrations are elevated above the modelled predictions."*

A total of 1,499 m of stream channel will be altered by mining and this will be replaced by 1,340 m of channel and a 0.4 ha lake.

Reports by *Fording Coal Ltd. (1992 and 1994)* discuss construction of the diversion pipes. However, no post construction reports describing the diversion channel could be located at the Ministry of Energy, Mines and Petroleum Resources Office in Victoria. Representatives of Fording Coal were also unable to return phone calls regarding this project. Discussions with Jim Allan of Pisces Environmental Consultants Ltd. suggest that the diversion channel may not yet have been constructed.

A8.4 KEMESS MINE, ROYAL OAK MINES LTD., B.C.

It was initially proposed to construct two channels around the waste rock dump at this minesite in northern B.C. One channel would collect seepage flows, while the other would be used to convey the natural drainage around the rock dump. Our information indicates that the waste rock pile has not yet reached the stream and the diversion channels have not been constructed *(Dave Bustard, R.P.Bio., pers. comm.)*. Once completed, it is anticipated that the diversion channel will provide habitat for Dolly Varden.

The numbers of rainbow trout and Dolly Varden in South Kemess Creek are believed to have increased since a mine site reservoir was constructed *(Dave Bustard, R.P.Bio., pers. comm.)*. This improvement is believed to have resulted from a more stable flow regime (due to reduced floods and winter releases of water) and possibly changes in the water temperature regime.

A8.5 FARO MINE, ANVIL RANGE MINING CORPORATION, YUKON

One of the authors (Miles) worked at the Faro Minesite in 1990. At that time there was a diversion channel around the pit and a portion of the waste rock dump. This channel drained into the north Fork of Rose Creek. As illustrated on *Plates A8.1 and A8.2*, this steep unlined channel was subject to massive erosion, particularly in the area where it dropped into Upper Vangorda Creek. The available information indicates that this channel was barren of fish *(Paul Harder, R.P.Bio., pers. comm.)*. This project is assessed as being a failure.

A much lower gradient channel was constructed around the tailings pond located in the Rose Creek valley bottom. Some sections of this channel were rock lined and drop structures were locally constructed to control velocity and grade. This channel supported low densities of grayling and/or whitefish *(Paul Harder, R.P.Bio., pers. comm.)*. This project is tentatively rated as a limited success.

Unusually high densities of grayling and whitefish were found in the natural stream channel downstream of the mine site reservoir *(Paul Harder, R.P.Bio., pers. comm.)*. This is similar to the reported increase in fish density below the Kemess Mine Reservoir (see SECTION A8.4).

A8.6 WEST JARVIS CREEK/PIT B6, CARDINAL RIVER COALS LTD., ALTA

The West Jarvis Creek coal mine is located south of Hinton, Alberta. The middle section of Sphinx Creek was diverted around the edge of the developed pit in a long culvert. It was thought that fish would not use or migrate through the culvert *(C. Hunt, pers. comm.)*. Fish were therefore captured at the culvert outlet and released in the basin headwaters.

Another section of Sphinx Creek was diverted around a settling pond located approximately 1 km downstream of Sphinx Lake. This channel has a 7% slope and 5 steps were constructed to facilitate fish access. *George Sterling (pers. comm.)* suggests that these structures are passable by bull trout, however, two of the steps may be a barrier to the smaller Athabascan strain of rainbow trout. This hypothesis is confirmed by recent fish sampling which indicates that there are bull trout but no rainbow trout in the section of channel between these structures and Sphinx Lake. On this basis, the project has been rated as having limited success *[George Sterling, pers. comm.]*.

A8.7 COAL VALLEY MINE, LUSCAR LTD., ALBERTA.

This mine is located south of Edson, Alberta. A tributary to Centre Creek, which previously held Arctic grayling, native Athabasca strain rainbow trout and stocked brook trout, was diverted around Pit 26 in July 1988. A 2.3 km long section of channel was extensively enhanced for fisheries production. Complexity was provided through woody debris and boulder placement, holding pools were created and spawning areas constructed. The entire channel was lined with pit run gravel. The channel cuts across a wetland complex which may help to regulate peak flows. The channel has successfully survived a number of large flood events without significant damage.

Fish spawn successfully and the channel produces large numbers of juvenile brook trout. Most fish appear to migrate to Centre Creek, possibly due to a lack of deep water or beaver dam habitat which occurred in the natural channel. Fish of up to 20 inches in length have, however, been taken from the channel. This channel is rated as an "outstanding success" *(D. McCoy, pers. comm.)*. [Information about this project was provided by RL&L Environmental Services Ltd., *Jim Allan and Dane McCoy, pers. comms.*].

On August 25, 1999, G. Hartman visited the Centre Creek project. The upper section of the project, about 1.5 km long, was located in a wetland. This section of the channel contained slow moving water and would have provided good trout rearing habitat. Below the wetland section, water flowed through a straight, V-shaped channel for about 0.6 km. There was little riparian cover and the estimated flow was 0.1 m^3/sec. This section of channel would have been subject to heating during summer and, potentially, to freezing during winter. It would therefore be desirable to evaluate seasonal temperature conditions within the channel.

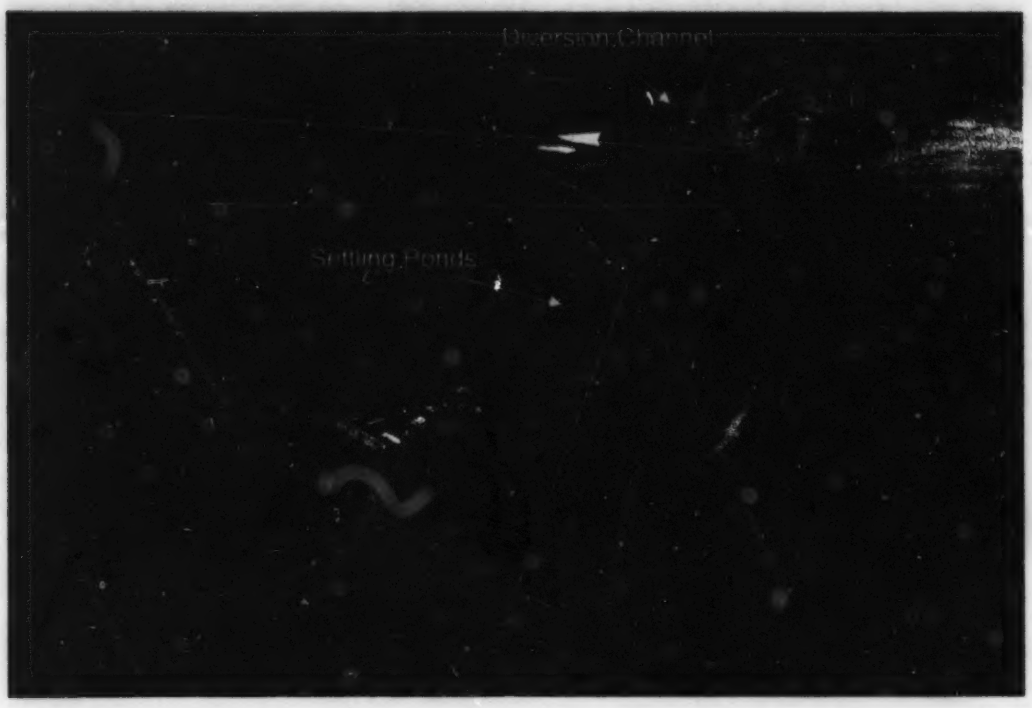
A8.8 EKATI DIAMOND MINE, BHP MINERALS LTD., NWT

The Ekati Mine is located near Lac de Gras, 300 km NE of Yellowknife. A 3.2 km long diversion channel was constructed around a series of lakes which were drained to allow mining. The channel was hydraulically designed to handle the expected flows and modified to provide habitat for arctic grayling. Small numbers of juvenile burbot are also using the channel. The summer of 1999 will be the second in a 10-year post-construction monitoring program. Graduate students are studying the hydraulics and biological conditions in the diverted channel and fish use is being compared to adjacent natural streams. Habitat stability and use is being monitored to determine what kinds of additional enhancement work would be beneficial. Ice damage to the channel has been identified as a potential concern. Based on the initially available data, this project is rated as a moderate success *(J. Dahl, pers. comm.)*. [Information on this project was provided by RL&L Environmental Consultants Ltd., *Margaret Keast and Julie Dahl*].

May 22, 1990 Looking upstream. MM 90 - 40 - 14A

Plate A8.1

Photograph of the diversion channel around the main pit and the waste rock dump at Anvil Range Mining Corporation's mine at Faro, Yukon (photo by M. Miles).



May 22, 1990 Looking upstream. MM 90 - 39 - 36

May 22, 1990 Looking downstream. MM 90 - 39 - 24

Plate A8.2

Photographs of the diversion channel around the tailings pond at Anvil Range Mining Corporation's mine at Faro, Yukon (photos by M. Miles).